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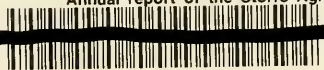
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THIRTEENTH ANNUAL REPORT

— OF THE —

STORRS

AGRICULTURAL EXPERIMENT STATION,

STORRS, CONN.

1900.

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PRINTED BY ORDER OF THE LEGISLATURE.

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MIDDLETOWN, CONN.:  
PELTON & KING, PRINTERS AND BOOKBINDERS.  
1901.

HIS EXCELLENCY GEORGE P. MCLEAN.

B. C. PATTERSON.

EXECUTIVE COMMITTEE.

TREASURER.

STATION STAFF.

The Station is located at Mansfield (P. O. Storrs), as a department of the Connecticut Agricultural College. The chemical and other more abstract research is carried out at Wesleyan University, Middletown, where the Director may be addressed.

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## Report of the Executive Committee.

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*To His Excellency George P. McLean,*

*Governor of Connecticut:*

In accordance with the resolution of the General Assembly concerning the congressional appropriations to the Agricultural Experiment Stations, and an Act of the General Assembly approved March 19, 1895, relating to the publication of the Reports of the Storrs Agricultural Experiment Station, we have the honor to present herewith the Thirteenth Annual Report of that Station, namely, that for the year 1900.

The accompanying report of the Treasurer gives the details of receipts and expenditures. We refer you to the report of the Director and his associates for a statement of the work accomplished during the past year.

Respectfully submitted,

G. A. HOPSON,	} <i>Executive</i>
G. S. PALMER,	
B. C. PATTERSON.	

*Committee.*

# Report of the Treasurer

FOR THE FISCAL YEAR ENDING JUNE 30TH, 1900.

The following summary of receipts and expenditures, made out in accordance with the form recommended by the United States Department of Agriculture, includes, first, the Government appropriation of \$7,500, and, secondly, the annual appropriation of \$1,800 made by the State of Connecticut, together with various supplemental receipts. These accounts have been duly audited according to law, as is shown by the Auditors' certificates, copies of which are appended.

## GOVERNMENT APPROPRIATION—RECEIPTS AND EXPENDITURES.

RECEIPTS.	
United States Treasury, - - - - -	\$7,500 00
EXPENDITURES.	
Salaries, - - - - -	3,778 40
Labor, - - - - -	958 67
Publications, - - - - -	78 40
Postage and stationery, - - - - -	260 50
Freight and express, - - - - -	72 62
Heat, light, and water, - - - - -	488 14
Chemical supplies, - - - - -	53 14
Seeds, plants, and sundry supplies, - - - - -	146 28
Fertilizers, - - - - -	127 95
Feeding stuffs, - - - - -	289 19
Tools, implements and machinery, - - - - -	1 20
Furniture and fixtures, - - - - -	407 31
Scientific apparatus, - - - - -	677 69
Live stock, - - - - -	17 24
Traveling expenses, - - - - -	61 62
Contingent expenses, - - - - -	10 00
Buildings and repairs, - - - - -	71 65
	<hr/>
	\$7,500 00

## AUDITORS' CERTIFICATE.

We, the undersigned, duly appointed Auditors of the State of Connecticut, do hereby certify that we have this day examined the books and accounts of William D. Holman, Treasurer of the Storrs Agricultural Experiment Station, for the fiscal year ending June 30th, 1900; that we have found the same well kept and classified as above, and that the receipts from the Treasurer of the United States are shown to have been \$7,500, and the corresponding disbursements \$7,500; for all of which proper vouchers are on file and have been by us examined and found correct, thus leaving no balance.

(Signed,) D. WARD NORTHROP, } *Auditors of the*  
WALTER A. RILEY, } *State of Connecticut.*

HARTFORD, CONN., Dec. 19, 1900.

STATE APPROPRIATION AND SUPPLEMENTAL RECEIPTS—  
RECEIPTS AND EXPENDITURES.

RECEIPTS.												
State of Connecticut,	-	-	-	-	-	-	-	-	-	-	-	\$1,800 00
Miscellaneous receipts,	-	-	-	-	-	-	-	-	-	-	-	1,684 75
												<u>\$3,484 75</u>
EXPENDITURES.												
Salaries,	-	-	-	-	-	-	-	-	-	-	-	\$2,119 17
Labor,	-	-	-	-	-	-	-	-	-	-	-	403 86
Publications,	-	-	-	-	-	-	-	-	-	-	-	45 23
Postage and stationery,	-	-	-	-	-	-	-	-	-	-	-	52 85
Freight and express,	-	-	-	-	-	-	-	-	-	-	-	45 70
Heat, light, and water,	-	-	-	-	-	-	-	-	-	-	-	130 47
Chemical supplies,	-	-	-	-	-	-	-	-	-	-	-	91 32
Seeds, plants, and sundry supplies,	-	-	-	-	-	-	-	-	-	-	-	29 54
Bacteriological investigations,	-	-	-	-	-	-	-	-	-	-	-	300 00
Furniture and fixtures,	-	-	-	-	-	-	-	-	-	-	-	26 50
Scientific apparatus,	-	-	-	-	-	-	-	-	-	-	-	221 01
Live stock,	-	-	-	-	-	-	-	-	-	-	-	6 80
Traveling expenses,	-	-	-	-	-	-	-	-	-	-	-	12 30
												<u>\$3,484 75</u>

AUDITORS' CERTIFICATES.

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(Signed,)      D. WARD NORTHROP, } *Auditors of the*  
                    WALTER A. RILEY, } *State of Connecticut.*

HARTFORD, CONN., Dec. 19, 1900.

We, the undersigned, duly appointed Auditors of the State of Connecticut, do hereby certify that we have this day examined the books and accounts of William D. Holman, Treasurer of the Storrs Agricultural Experiment Station, for the fiscal year ending June 30th, 1900; that we have found the same well kept and classified as above, and that the receipts from miscellaneous sources are shown to have been \$1,684.75, and the corresponding disbursements \$1,684.75; for all of which proper vouchers are on file and have been examined and found correct, thus leaving no balance.

(Signed,)      D. WARD NORTHROP, } *Auditors of the*  
                    WALTER A. RILEY, } *State of Connecticut.*

HARTFORD, CONN., Dec. 19, 1900.

W. D. HOLMAN, *Treasurer.*

## Report of the Director for the Year 1900.

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The principal inquiries now being conducted by the Station have to do with the nutrition of plants, animals, and man, and with the bacteriology of the dairy. During the year 1900 they have included experiments on the effects of fertilizers upon the growth and composition of plants, studies of the rations fed to milch cows, experiments upon the ripening of cream, studies of bovine tuberculosis, and investigations on the food and nutrition of man. The objects, methods, and results of inquiries in these lines are given in this Report. Not all the work done during the year, however, is described in the present volume, as some of the results are not yet ripe for publication. On the other hand, some of the articles report the work of more than one year.

### FIELD AND POT EXPERIMENTS WITH FERTILIZERS.

*Soil tests.*—These tests have been carried on at Storrs continuously for eleven years upon the same field. The plan consists in dividing the field into parallel plots on which different fertilizers are applied, and repeating the experiments with the same fertilizers on the same plots year after year, but with different crops—corn, potatoes, oats, and either cow peas or soy beans, grown in a four-year rotation. The object of the tests is to get light upon the capacity of the soil to supply nitrogen, phosphoric acid, and potash, the particular needs of the different crops for any or all of these ingredients, and the most economical method of supplying them. From the results obtained during the eleven years on this particular field, it appears that the fertilizing ingredients most needed have varied with the crop. That is to say, the peculiarities of the plant have had as much or more to do with deciding the demand for fertilizers than any special deficiency of the soil. Cow peas and soy beans have been benefited by phosphoric acid and potash, but have paid little heed to nitrogen. Corn and oats have responded well to nitrogen, and both have been helped by



phosphoric acid, but neither has been much increased by potash. Potatoes have been benefited by all three ingredients, and especially helped by potash.

*Special nitrogen experiments.*—Nitrogen in fertilizers may be of advantage in two ways: it may increase the total yield of the crop, and it may also increase the proportion of nitrogenous compounds, *i. e.*, protein, in the crop. This latter effect of nitrogenous fertilizers has been but little understood in the past; the so-called "special nitrogen" experiments carried on by the Station are helping to bring it out more clearly. The object of these experiments is to study the effects of the nitrogen of different fertilizers upon the yield, and especially the composition of the crop. In making the experiments the crops are grown on a series of parallel plots, some of which are supplied with definite quantities of mineral fertilizers alone, while others have different quantities of nitrogen in addition to the minerals. The effect of the nitrogenous fertilizers upon the total yield of the crop is estimated by comparing the yields from the plots having the mineral fertilizers alone with the yields from the plots having the nitrogenous fertilizers in addition to the minerals. The effect of the nitrogen of the fertilizers upon the composition of the crop, and especially upon the proportion and amount of protein, is estimated in like manner by sampling and analyzing the crops from the different plots. These experiments are carried out with corn, cow peas, and soy beans. They indicate that with the cereals the effect of the nitrogenous fertilizers is to increase not only the total yield of the crop, but also the proportion of protein, and thus, in a two-fold way, to increase their feeding value. With the legumes, on the other hand, the nitrogenous fertilizers have very little effect upon either the amount or the composition of the crop.

Experiments for the study of the effects of nitrogenous fertilizers upon the proportions of nitrogen in different species of plants have been made on a small scale in such a way that moisture and other external influences might be more completely under control. In these experiments the plants are grown in pots by the use of the same kinds of nitrogenous and other fertilizers as are used in the plot experiments mentioned above, the total produce being weighed and taken for analysis.



*Experiments with forage crops.*—The object of these experiments, which have been continued at Storrs for several years, is to get light upon the fitness of certain forage crops for use in Connecticut. The experiments have had to do with the growth of these crops and the effects of nitrogenous fertilizers upon their growth and nitrogen content. Studies have also been made of their composition and digestibility and their comparative value as fodders.

*Experiment on soil improvement.*—In 1899 an experiment was undertaken to study and compare the economy of different methods of manuring for restoring fertility to a soil that appears to be lacking in organic matter and in available nitrogen, such a soil as is commonly spoken of as “poor” or “worn out.” This experiment is being continued.

#### DAIRY BACTERIOLOGY.

For several years past Prof. Conn and Mr. Esten have been engaged in the study of the bacteria which grow in cream during its ripening. The results of this work are given in the present Report, and may be briefly summarized as follows:

It is found that the bacteria which get into milk during the milking are quite numerous in variety. Of those which are present in milk and cream at the outset there are only very few which produce lactic acid, while there are large numbers of other miscellaneous bacteria. During the first twelve hours or more the miscellaneous bacteria increase somewhat rapidly. The few lactic bacteria which are present at the outset find the milk such a favorable medium for growth that they multiply more rapidly than the others, and soon surpass in numbers all the miscellaneous bacteria which at first were so much more abundant. The lactic bacteria continue to grow during the ripening, for about 24 to 36 hours, while the miscellaneous bacteria become less and less abundant. By the time the cream is properly ripened the lactic bacteria comprise usually 98 per cent. of the whole, and in many cases they seem to have totally destroyed all other species. If the cream is allowed to ripen for two to three days the number of these lactic bacteria continues to increase until it frequently reaches one and one-half billion per cubic centimeter. After this they begin to

decrease rapidly in numbers, and a few days later only a few bacteria of any kind are left alive in the cream.

There is thus apparently a battle going on in the cream between the different species of bacteria. In the first twelve hours the miscellaneous species continue to multiply. During this time the few lactic bacteria grow rapidly and soon obtain the upper hand, eventually destroying the miscellaneous forms almost entirely. Later the lactic bacteria themselves seem to be destroyed by the products of their own activity.

These experiments by Prof. Conn are in a new field of inquiry, which it is hoped will ultimately give to butter-makers a more satisfactory explanation of the proper method of handling "starters." The experiments thus far have not indicated positively which of the types of organisms are most concerned in cream ripening. That the lactic bacteria play an important part in the ripening is evident, but there are reasons for believing that the multiplication during the first twelve hours of the miscellaneous bacteria, which do not produce acid, is a phenomenon of great importance in determining the character of the flavors and aromas of the ripened product. The study of this problem is to be continued by the Station.

#### BOVINE TUBERCULOSIS.

The tuberculous cows which had been under observation in quarantine at the Station since 1896 were slaughtered during the past year. Some of the calves that were being fed upon the milk of these cows were kept for several months after the cows were killed, in order to observe whether any secondary cases of tuberculosis would develop among them. With the slaughter of these calves the study of bovine tuberculosis with these animals comes to an end. An article summarizing the results of the tests and the conclusions from them will be prepared.

#### FEEDING EXPERIMENTS WITH DAIRY HERDS.

The studies of rations fed to milch cows, and their effects upon the milk production, have been continued during the past year. The object of these experiments is to learn how representative dairy farmers in different parts of the State feed their cows, to compare their methods and the results obtained by them with the methods and results of experiments elsewhere,

and make suggestions for improvements. At the same time the experiments bring new and valuable information regarding economical feeding of cows for the production of milk and butter. The experiments of the previous years have pointed quite clearly to the value of rations with a narrow nutritive ratio, that is with large proportions of protein, for the production of milk and butter. Wherever a wide ration has been found in use an increase of the nitrogenous feeding stuffs has been proposed, and usually with profitable results so far as the short experiments indicated. It is encouraging to observe that these facts are apparently becoming more familiar to dairy farmers. In a number of cases, during the experiments of the past year, the ration in use was found to be so well balanced that but little change could be suggested, and the results of the tests as regards improvement in production of milk or butter were consequently less marked than in former years.

#### FOOD AND NUTRITION OF MAN.

The inquiries on the food and nutrition of man carried on by the Station in coöperation with the United States Department of Agriculture for several years past have been continued. These include analyses of food materials, studies of dietaries of different classes of people, digestion experiments with men, determinations of the fuel values of food materials, and experiments with men in the respiration calorimeter. With the exception of the dietary studies, investigations in each of these lines have been made during the past year. The determinations of the composition, digestibility, and fuel values of food materials were made in connection with the metabolism experiments with men in the respiration calorimeter. Twelve metabolism experiments were made during the past year, the details of which will appear in other publications. Some of the results of the work are given in the present report. Arrangements are now being made for similar experiments with domestic animals.

#### ANALYSES OF FOODS, FEEDING STUFFS, ETC.

In connection with the inquiries of the Station, a large number of chemical analyses are required. These include analyses of crops grown in the tests with fertilizers, and of foods and other materials used in the metabolism experiments with man.

In addition to the chemical analyses of the various foods, feeding stuffs, etc., the heats of combustion of a large number of specimens have also been determined.

#### METEOROLOGICAL OBSERVATIONS.

The usual observations of temperature, barometric pressure, wind velocity, humidity and precipitation have been made at Storrs. In addition, records of rainfall during the growing season have been made in other places in different parts of the State by farmers who have coöperated with the Station.

#### EXHIBIT OF THE STATION AT THE PARIS AND BUFFALO EXPOSITIONS.

The exhibit prepared by the Station for the Paris Exposition of 1900, consisting of a cabinet of forty-eight cultures of bacteria isolated from various dairy products, prepared by Prof. Conn, a bomb calorimeter with all its accessory apparatus, and a model of the respiration calorimeter, were returned from Paris and have been installed with the exhibits of other Experiment Stations and the Department of Agriculture at the Pan-American Exposition at Buffalo. In recognition of the value of the researches represented by the exhibit at Paris, a gold medal was awarded to the Director of the Station.

#### DISSEMINATION OF INFORMATION.

Considerable attention is given to the dissemination of the results of the work of the Station. Annual Reports and Bulletins are published and distributed throughout the State and elsewhere. The Reports contain the more technical details of the investigations for permanent record and for the especial use of those particularly interested in such matters, while the Bulletins are of a more popular nature and present the practical side of the results of the work. The latter are printed in larger numbers than the former. During the past year a Bulletin by Prof. Phelps on the "Soy Bean as a Forage Crop" was issued.

The Station has also an extensive correspondence, letters being written in answer to questions concerning the work which come not only from Connecticut and other parts of the United States, but also from foreign countries. In addition to this, members of the Station Staff give frequent lectures and addresses before institutes, conventions, and other meetings of farmers and dairymen.

W. O. ATWATER, *Director.*



## THE RIPENING OF CREAM.

BY H. W. CONN AND W. M. ESTEN.

## THE OBJECT OF THE EXPERIMENTS.

Experiments upon the ripening of cream that have been carried out in this laboratory and elsewhere in past years have been confined largely to efforts to separate from milk or cream different species of bacteria, and then by inoculating pasteurized cream with pure species of the isolated organisms, to determine the influence that each species might have upon the cream if acting alone. These experiments have resulted in showing that different milk bacteria vary decidedly in their influence upon the character of butter. Hitherto, however, no description has been given of careful experiments showing the exact bacteriological condition of normal cream before it is ripened, or the change in bacteriological content that occurs during the ripening.

The object of the experiments here described has been to determine so far as possible the types of bacteria which produce the ripening of cream under the *normal* conditions of a Connecticut dairy. Manifestly there is an advantage in determining the actual changes that occur in cream in normal ripening; and for practical purposes the results of these investigations may possibly be of more value than those of experiments with pure cultures. They may be of importance in at least two ways: First, they may settle the question over which there has been some dispute, as to whether the acid organisms alone are concerned in cream ripening, or whether the non-acid species may assist in producing good butter; and second, they may be of aid in determining how to handle starters, by pointing out a more satisfactory method of obtaining artificial cultures for cream ripening, which shall produce results more in harmony with those desired than are obtained by the use of any culture now employed by dairymen.

Probably the reason that such experiments have not been undertaken hitherto lies in the extreme difficulty in carrying

them out with any degree of satisfaction. It is exceedingly difficult to determine the types of bacteria in a culture containing so many millions of organisms per cubic centimeter as are found in ordinary cream. The work involved is excessive and the results obtained seem to be rather small. The experiments which formed the basis of this article have occupied a considerable portion of the time for three years in the bacteriological work in this laboratory. But although they have been extended over such a long period, the results are not yet wholly satisfactory. The experiments particularly described below number about forty, but this represents only a very small part of the total number. The early experiments were of use only in suggesting problems and in pointing out methods of work, and inasmuch as they were of no especial significance in the general result, because of imperfect methods, they have been wholly omitted from our descriptions. After a moderately satisfactory method was determined further tests of cream were made in large numbers, and they have yielded quite constant results, with certain exceptions, which will be noted. The constancy of these results, which have been obtained now in two score or more of similar experiments, leads to the conclusion that, in spite of the necessary imperfection of the method, the results may be relied upon as expressing approximately the truth in regard to the problem studied. It should be added that the methods that are employed are being constantly improved, and at the present time a greater accuracy is possible than in the earlier part of the work. The experiments are still going on and will be continued for some time longer, but it has been deemed wise to publish at this time the general result of the work of the last three years upon this subject.

The significance of this series of experiments may be understood from another consideration. As is well known, there have been put upon the markets in the last ten years quite a large number of pure cultures for cream ripening, some of which have been used very widely. In the countries of northern Europe the use of such pure cultures has rapidly extended, and in Denmark it is practically universal. But although quite a number of such cultures have been used, there is no one of them which produces results that are wholly satisfactory, at

least to the American market. In general it may be stated that the cultures used produce a good quality of butter, but one with an extremely mild flavor and aroma. Such butter does not possess the character of the best type of butter ripened by natural conditions. It has been believed that the reason for this is that the normal butter flavors are not produced by any one type of bacteria, and that consequently the taste of butter ripened under natural conditions and, therefore, under the influence of a considerable variety of bacteria, is better than that produced under the influence of a pure culture which is a single species. This has been, however, up to the present time wholly a matter of theory, for no one has studied the ripening of cream under *normal* conditions sufficiently to know whether or not there is a multiplication of a large number of types of bacteria, or whether in reality the ripening is produced by a single species. If this question can be settled, manifestly it will contribute largely toward enabling bacteriologists to improve the types of cultures which can be used for artificial cream ripening.

#### METHOD OF EXPERIMENT.

The experiments upon which this paper is based were performed upon cream obtained from two creameries and four private dairies. Each creamery experiment was performed as follows: A visit to the creamery was made at such time as made it possible to obtain a sample of the cream freshly brought into the creamery, and, therefore, just before it is set for ripening. The cream sample was put upon ice, was at once carried to the laboratory, and was plated as soon as possible, always within two hours of the time of collection. Before it was plated the cream was diluted commonly with 100,000 to 250,000 parts of sterilized water, though with very fresh cream smaller dilutions were used. These dilutions, of course, were very large and introduced certain errors, but they were found necessary to make possible a satisfactory determination of the number of bacteria on the plates. Upon the next day a second visit was made to the creamery and a sample of the same cream ripened was obtained just before the time of churning. This was in a similar way placed upon ice, brought to the laboratory and plated. In this way two series of plates

were made from the same lot of cream, before and after ripening, and they could, therefore, within the necessary limits of such experiments, be directly compared with each other.

After a little experimenting it was found that results identical with these could be obtained if a small amount of the unripened cream, about a pint, was brought to the laboratory and allowed to ripen there at a temperature similar to or slightly higher than that at which the cream ripened in the creamery. A sufficient number of comparative experiments were made to show that the results of the ripening in the two cases were practically identical; therefore in the later experiments the ripening was always performed in the laboratory rather than in the creamery.

The culture medium used was a gelatin nutrient solution to which had been added three per cent. of milk sugar, inasmuch as it is found that the milk bacteria grow much better in a milk sugar medium. While the materials were being boiled in preparing the solution there was added about three per cent. dry litmus to the mixture, which gave a moderately blue color to the gelatin solution when finally completed. Occasionally plates were made of ordinary gelatin without milk sugar or litmus, for comparison, in order to determine whether any larger number of bacteria developed in the milk sugar gelatin than in ordinary gelatin. There was found to be very little difference between the numbers on the two sets of plates, although the cultures were larger and more robust in the milk sugar gelatin.

#### GROWTH OF BACTERIA DURING CREAM RIPENING.

The first point to be noticed was the actual number of bacteria found in the unripened and the ripened cream. In the following tables are given the results of such experiments with cream from three different sources.

*Cream from private dairy.*—Cream of three or four days' gathering was placed in a cellar each day as collected. About twenty-four hours before churning it was brought from the cellar and placed in a room near a stove, where it gradually warmed to about 70° F. No definite temperature of ripening. First samples were taken of cream when brought out to ripen, and second samples when just ready to churn.



TABLE I.

*Number of bacteria in unripened and ripened cream.*

DATE.	In unripened cream.	In ripened cream.
	Per c. c.	Per c. c.
November, - - - - -	87,000,000	400,000,000
January 10, - - - - -	*	187,000,000
January 12, - - - - -	135,000,000	203,000,000
January 23, - - - - -	88,000,000	145,000,000
January 26, - - - - -	132,000,000	390,000,000

\* Too small to be calculated with the dilution used.

*Cream from small creamery.*—Cream from several farmers collected every day. 'Two days' collection kept in a vat for about twelve hours after being warmed with steam at a temperature varying with conditions from 65–70° F. First samples were taken just before ripening began, placed at low temperature (45° F., or were sometimes frozen), and were kept at this temperature about twelve hours before plating. Samples of ripened cream were plated at about time of churning.

TABLE 2.

*Number of bacteria in unripened and ripened cream.*

DATE.	In unripened cream.	In ripened cream.
	Per c. c.	Per c. c.
February 13, - - - - -	23,000,000	65,000,000
February 16, - - - - -	3,600,000	269,000,000
February 21, - - - - -	180,000,000	485,000,000
February 22, - - - - -	220,000,000	468,000,000
February 27, - - - - -	1,100,000	400,000,000
March 1, - - - - -	1,500,000	578,000,000
March 3, - - - - -	5,500,000	486,000,000
March 4, - - - - -	15,000,000	50,000,000

*Cream from large creamery.*—Cream from many dairies collected every two days. Reached the creamery about 12 o'clock. Sample was taken at once, placed on ice, and plated about 3 p. m. Mixed cream in creamery was warmed to about 65° F., and ripened about twelve to twenty-four hours, after which second sample was taken.

TABLE 3.  
*Number of bacteria in unripened and ripened cream.*

DATE.	Temperature during time of ripening.	In unripened cream.	In ripened cream.	Remarks.
		Per c. c.	Per c. c.	
Oct. 28,	- - -	125,000,000	350,000,000	—
May 22,	64° for 20 hrs.	56,000,000	354,000,000	—
May 26,	64-68°, 20 "	60,000,000	320,000,000	Good aroma.
May 29,	66°, 18 "	186,000,000	295,000,000	Good aroma, gas.
July 2,*	60-70°, 16 "	214,000,000	380,000,000	Good aroma.
July 5,*	63-65°, 16 "	178,000,000	392,000,000	{ Good aroma, thick, slightly acid.
July 12,*	71°, 17 "	67,000,000	190,000,000	Good aroma, acid.
July 16,*	71°, 16 "	134,000,000	243,000,000	—
July 19,	71°, 14 "	75,000,000	286,000,000	Slow ripening.
July 22,	- - -	115,000,000	428,000,000	—
Oct. 13,	68°, 18 "	72,000,000	291,000,000	—
Oct. 30,	60-65°, 28 "	107,000,000	199,000,000	—
Nov. 3,	- - -	39,000,000	234,000,000	—
Dec. 8,	60-70°, 29 "	4,000,000	238,000,000	—
Dec. 11,	60-70°, 24 "	35,000,000	200,000,000	—
Oct. 19,	60-70°, 24 "	39,000,000	380,000,000	—
Oct. 26,	60°, 21 "	115,000,000	297,000,000	Ripe when collected.
Nov. 2,	- - -	158,000,000	355,000,000	—

\* Hot weather.

From these tables it will be seen that the number of bacteria present in the unripened cream is very much more variable than that present in the ripened cream. In the unripened cream the number was sometimes as small as one million per cubic centimeter, and in one case it was so small that it could not be determined with the high dilutions which were used. At the other extreme we have one sample of unripened cream collected in February with 220 million bacteria per cubic centimeter. In the other experiments the figures range between these. The significance of this fact is, of course, simply that the cream as collected in the creamery, which we speak of as unripened, is really in different stages of ripening by the time it reaches the creamery. The samples with large numbers of bacteria are already well ripened, while those with small numbers have only begun their ripening process.

The number of bacteria in the ripened cream varies far less. The smallest number found was 50 millions; the largest number, 578 millions. While this difference is of course in actual

numbers a large one, the proportionate difference is very much less than in the unripened cream; one sample of unripened cream, for instance, containing two hundred and twenty times as many bacteria as another sample, while the largest number in the ripened cream was only about eleven times as great as the smallest number.

The only conclusions of any significance from these facts are that the cream received by creameries is in various stages of ripening, and secondly, that the number of bacteria in ripened cream does not run much over 500 million per cubic centimeter. In the well ripened cream this number is rarely surpassed.

#### INCREASE OF ACID PRODUCING ORGANISMS.

The next problem was to determine the proportion of species producing acid to those not producing acid. This determination is quite easy by the use of the litmus gelatin, in all cases where liquefying organisms are not present in great abundance. If the plates are allowed to grow for three or four days every acid producing organism is easily determined by its being surrounded by a red halo where the litmus has been changed by the acid. It is a very easy matter to go over the series of plates and thus determine the proportion of bacteria producing an acid reaction. The results of about twenty-five experiments in regard to this problem are shown in the following table. This table includes only results with cream from two creameries, the results with cream from the private dairies being given on a later page.

It will be noticed from Table 4 that in most cases the percentage of acid organisms increased during the ripening. In the unripened cream the percentage of acid organisms is quite variable. The lowest percentage given in the table is 66. From 66 per cent. the proportion of acid organisms varies to as high as 100 per cent. in a single specimen. In most cases the percentage of lactic organisms in the unripened cream is over 95 per cent., and not infrequently as high as 99 per cent.

The ripened cream, on the other hand, shows uniformly a higher percentage of acid organisms. In each of the experiments (with one exception) given in the table the number of acid organisms is over 97 per cent.; in all but four it is over 99

per cent., and in most cases it is closely approximating 100 per cent. Even in experiments where the number of acid organisms in the unripened cream was lowest the number present in the ripened cream has risen to 98 and 99 per cent. This, of course, indicates that, in these experiments at all events, the ripening has consisted essentially in the growth of organisms producing some kind of acid, at the expense of those giving an alkaline reaction or no reaction at all.

TABLE 4.

*Percentage of acid organisms in cream from two creameries.*

DATE.							In unripened cream.	In ripened cream.
<i>Small Creamery.</i>							%	%
Feb. 13,	-	-	-	-	-	-	98.0	99.0
Feb. 15,	-	-	-	-	-	-	94.0	99.0
Feb. 20,	-	-	-	-	-	-	98.5	99.0
Feb. 22,	-	-	-	-	-	-	90.0	99.0
Feb. 27,	-	-	-	-	-	-	66.0	99.0
March 1,	-	-	-	-	-	-	75.0	98.0
March 3,	-	-	-	-	-	-	99+	99+
March 4,	-	-	-	-	-	-	100.0	100.0
May 22,	-	-	-	-	-	-	99.7	99.9
May 26,	-	-	-	-	-	-	99.2	99.8
<i>Large Creamery.</i>								
May 29,	-	-	-	-	-	-	96.0	99.6
June 2,	-	-	-	-	-	-	99.2	99.8
June 5,	-	-	-	-	-	-	99.5	100.0
June 12,	-	-	-	-	-	-	99.5	99.9
June 16,	-	-	-	-	-	-	98.5	99.2
June 19,	-	-	-	-	-	-	98.0	99.7
June 22,	-	-	-	-	-	-	97.7	99.6
Oct. 13,	-	-	-	-	-	-	97.5	96.5
Oct. 30,	-	-	-	-	-	-	99.3	99.6
Nov. 3,	-	-	-	-	-	-	99.3	99.6
Dec. 8,	-	-	-	-	-	-	90.0	99.5
Oct. 19,	-	-	-	-	-	-	74.0	98.5
Oct. 26,	-	-	-	-	-	-	95.0	97.7
Nov. 2,	-	-	-	-	-	-	98.0	97.7

## SPECIES OF BACTERIA.

We next made an attempt to determine more accurately the species of bacteria which are chiefly concerned in the normal ripening. This has been the most difficult part of the work and one in regard to which we have as yet the least satisfactory results. The difficulty of determining with any degree of

accuracy the species of bacteria present in cream when the total number mounts up into the hundreds of millions per cubic centimeter is very great. It can of course be accomplished only by the study of the colonies upon the gelatin plates and differentiating these as well as possible. After long experimenting we found it possible to do this to a certain extent. When the plates are made with milk sugar-litmus gelatin there are four types of acid colonies produced. One of these is that characteristic of the common *B. acidi lactici* (No. 206 of our list described in a previous report\*), easily recognized from its being intensely acid, robust, growing under the surface of the gelatin, but not on the surface, and showing on its edge minute radiating projections. A second (No. 202 of our previous list), is an extremely minute colony, also growing under the surface of gelatin, commonly transparent and smooth and intensely acid. The third (No. 208 of our list), is *B. lactis aerogenes*, and is characterized by an extremely intense acidity, a very robust, large colony with a dense surface growth, and frequently producing gas bubbles. These three are readily distinguishable. A fourth acid type we have been obliged to refer to as miscellaneous acids, for it consists of all colonies showing acid reaction but not having the type of one of the three mentioned. In our experiments, the colonies of this fourth class have been few in unripened cream, and almost never present in the ripened cream. Their numbers are so small that they have been omitted in the following tables. The acid bacteria of ripened cream, in other words, consist of a mixture of the three organisms referred to, Nos. 206, 202 and 208. So large a proportion of the bacteria present in ripened cream do these three organisms form that all others must be regarded as incidental.

While these three species have thus shown themselves very abundant and easy to differentiate, we are by no means convinced that this classification represents three distinct species. Indeed, we have abundant evidence that each represents a type rather than a species. As is explained in a previous publication,<sup>†</sup> there are numerous varieties of the *B. acidi lactici*, varying in several points, especially in the amount of acid

\* Report of Storrs Station, 1899.

† *Idem*.



produced. The same is even more distinctly true of No. 208, for the organisms that we have in these experiments regarded as *B. lactis aërogenes* show variations too great to allow us to regard them as a single species. A more careful differentiation of this type of bacteria is to be undertaken in our laboratory, but in these cream ripening experiments any further differentiation has been impossible.

In addition to these there is in ripening cream a fifth group of bacteria which we have in general called Miscellaneous. They agree only in not producing acid. Commonly they produce a solution with an alkaline reaction, although sometimes there is no reaction. Some of them liquefy the gelatin while others do not. They consist of quite a number of different species, comprising more varieties than the acid bacteria. From the tables it will be seen that the number of these miscellaneous bacteria is very small in ripened cream, a fact which led us to believe at first that they have little to do with the cream ripening, although later experiments have made us doubt the correctness of this conclusion.

Table 5 gives the results of experiments with cream from a large creamery, extending from October to May, 1900, and two experiments in January, 1901. The results are expressed in percentages instead of in actual numbers of bacteria.

TABLE 5.

*Percentages of chief types of bacteria in cream from a large creamery.*

DATE.	IN UNRIPENED CREAM.					IN RIPENED CREAM.				
	No. 206.	No. 202.	No. 208 +3cc.	Total acid.	Miscellaneous.	No. 206.	No. 202.	No. 208 +3cc.	Total acid.	Miscellaneous.
	%	%	%	%	%	%	%	%	%	%
Oct. 19, - - - -	51.6	10.4	1.9	64.3	35.7	63.6	35.6	.5	99.7	.3
Oct. 26, - - - -	77.0	14.3	3.5	94.8	5.2	73.0	24.0	.7	97.7	2.3
Nov. 2, - - - -	71.0	23.0	3.9	97.9	2.1	77.5	19.0	1.1	97.6	2.4
Oct. 30, - - - -	50.0	35.0	10.0	95.0	5.0	55.0	41.0	2.5	98.5	1.5
March 23, - - - -	44.0	2.0	6.0	50+	50—	88.0	10.0	?	98+	2—
May 4, - - - -	52.0	3.3	2.0	87.0	13.0	66.0	26.0	.2	94.0	6.0
Jan. 19, - - - -	33.0	12.0	7.0	52.0	48.0	77.0	17.0	.5	99.0	1.0
Jan. 28, - - - -	75.0	?	9.0	84.0	14.0	89.0	?	.2	91.0	9.0

From this table five important results may be noticed as follows:

1. In all of the experiments recorded there has been, during the ripening, an increase in the percentage of acid producing bacteria. Whereas the number in the unripened cream varies from 50 to 97 per cent., the number in the ripened cream in no case falls below 91 per cent. and is commonly from 97 to 100 per cent.

2. There is a nearly uniform increase in the percentage of the common lactic bacteria No. 206 (*B. acidi lactici*).

3. There is usually an increase in percentage of the second common lactic bacteria No. 202.

4. There is generally a slight decrease in the percentage of the No. 208 (*B. lactis aerogenes*), which, though common in all samples, does not occur in very large numbers.

5. The Miscellaneous alkaline group of bacteria in these experiments forms a much larger per cent. than in the experiments of Tables 1-4, but there is a universal decrease in their percentage during the ripening.

In order to compare these results obtained with the cream from a creamery with those obtained with cream from a private dairy, the results of three preliminary experiments made with cream from two small dairies are given in the following table. The cream from the dairies was gravity cream and therefore not so fresh as centrifugal cream would be, but was fresher than the cream obtained from the creamery.

TABLE 6.

*Percentages of chief types of bacteria in cream from private dairies.*

DATE.	IN UNRIPENED CREAM.					IN RIPENED CREAM.				
	No. 206.	No. 202.	No. 208.	Total acid.	Miscellaneous.	No. 206.	No. 202.	No. 208.	Total acid.	Miscellaneous.
	%	%	%	%	%	%	%	%	%	%
Jan. 4, - - - -	5.0	2	0	7+	93	96	1	0	97	3
Jan. 28, - - - -	9.2	?	?	9	91	86	12	—	98	2
Feb. 4, - - - -	1.0	?	?	1	99	59	2	3	62	38

In comparing the experiments in Table 6 with those given in Table 5, two very striking differences are to be seen:

1. The number of acid bacteria present in the unripened cream from the private dairy is extremely small. In these three experiments the proportions of acid bacteria were respectively 7, 9, and 1 per cent. The actual numbers were also very small.

2. On the other hand, the number of miscellaneous bacteria in the cream from the private dairy was very large, the proportions being 93, 91, and 99 per cent.; while in the cream from the creamery the proportions were much smaller.

The interpretation of these phenomena is very evident. It simply means that in these three experiments with cream from the private dairy the cream was obtained in a very much fresher condition than that which was found in the creamery. It was taken directly from a Cooley creamer in each case. The great contrast between the samples of unripened cream from the private dairy and those obtained from the creamery confirms the view that the cream as it is obtained in the creamery is always in a partially ripened state, and that in order to understand completely the process of ripening, attention must be turned to fresh cream. Such fresh cream can be obtained only from private dairies. This conclusion has led us to undertake a series of experiments of quite a different character.

#### RIPENING OF CREAM FROM PRIVATE DAIRIES.

Experiments have been carried on with the cream from four private dairies. The cream was separated by the gravity method in all cases, but was always obtained in a much fresher condition than in the earlier experiments, being the freshest obtainable. The first series of plates were made within two or three hours from the time the cream was separated from the milk. That it was quite fresh is indicated by the comparatively small number of bacteria present, as shown in the first line of the first column of Table 7. In some cases the number of bacteria was so small that with the dilutions used they could not be satisfactorily estimated. After the first plates were made the cream was set to ripen at a normal ripening temperature, about 68° to 70°. A second plate was made at the end



of 12 hours, another in 24 hours, and others at intervals of 12 hours for a period covering 84 hours. Thus eight analyses were made of each sample of cream at intervals of 12 hours. It was thought that the study of the series of plates thus made would give a picture of the changes that take place in the cream during its ripening, and would show more satisfactorily than any isolated experiments the bacterial development in the cream ripening. The following table represents the results of nine experiments of this sort performed with cream from four different dairies. It will be noticed that whereas there are some points of difference in the numbers, the general results of the analyses in all cases are practically identical, a fact of especial significance since they extended over five months (February to June) and were from four dairies.

An interrogation point inserted in the table means that the number of bacteria in question was so small as to fall below one per cent. Sometimes they were wholly absent, and always too few to be included in the general averages.

The organism indicated by an N. in the heading of the third column was a very common, non-liquefying bacterium which produced an alkaline reaction. As shown by the table it was always present in the unripened cream, but disappeared almost completely in a few hours.

The cream in the last three experiments developed a typical June aroma and flavor. In experiment No. 7 it was partly ripe when received. In the others a great growth of liquefiers is seen in the early ripening.

TABLE 7.  
*Variations in the proportions of the different types of bacteria during ripening.*

EXPERIMENT, DATE AND AGE OF CREAM.	Total number of bacteria per cubic centimeter.	PROPORTION OF DIFFERENT TYPES OF BACTERIA IN THE CREAM.					
		Liquefying bacilli.	N (non-lique- fying bacte- rium).	B. 206.	B. 208.	B. 202.	Miscella- neous.
<i>Experiment No. 1.</i> <i>March 20, 1901.</i>		%	%	%	%	%	%
Fresh, - - -	2,300,000	4.5	88.0	—	7.5	—	—
12 hours, - - -	47,000,000	2.0	16.0	23.2	37.4	—	21.4
24 hours, - - -	261,000,000	1.4	15.0	50.5	21.9	—	11.2
36 hours, - - -	417,000,000	.9	2.4	84.1	1.2	2.4	9.0
46 hours, - - -	56,800,000	1.6	11.3	84.8	.8	.5	1.0
70 hours, - - -	68,000,000	?	.7	98.5	?	—	.8
<i>Experiment No. 2.</i> <i>April 10, 1901.</i>							
Fresh, - - -	1,700,000	10.7	81.0	6.1	2.2	—	—
12 hours, - - -	79,000,000	1.6	12.8	76.5	3.1	—	6.0
24 hours, - - -	*	—	—	—	—	—	—
37 hours, - - -	911,000,000	—	.3	99.4	.3	—	—
48 hours, - - -	605,000,000	.1	.7	99.2	—	—	—
60 hours, - - -	817,000,000	?	?	97.5	?	2.5	?
72 hours, - - -	438,000,000	?	?	96.5	?	3.5	?
84 hours, - - -	408,000,000	?	?	94.0	?	6.0	?
<i>Experiment No. 3.</i> <i>April 27, 1901.</i>							
Fresh (12 hours), -	6,700,000	2.4	35.5	56.1	.7	—	5.3
12 hours, - - -	66,600,000	.1	17.3	72.0	1.5	—	9.1
24 hours, - - -	280,000,000	.4	10.7	78.6	2.1	—	8.2
36 hours, - - -	450,000,000	?	3.9	83.3	1.5	11.3	—
48 hours, - - -	905,000,000	?	2.8	89.3	.6	7.3	?
60 hours, - - -	666,000,000	?	1.7	89.7	.5	8.2	?
72 hours, - - -	555,000,000	?	2.2	87.3	?	10.5	?
84 hours, - - -	553,000,000	?	.7	77.0	?	22.3	?
<i>Experiment No. 4.</i> <i>February 19, 1901.</i>							
Fresh (3 hours), -	195,700	6.4	66.2	6.2	7.6	?	13.6
12 hours, - - -	4,750,000	11.8	70.2	5.1	1.8	?	11.1
24 hours, - - -	59,000,000	2.1	33.8	37.4	5.1	?	21.4
36 hours, - - -	528,000,000	.1	4.7	90.2	5.0	?	?
48 hours, - - -	1,023,000,000	.2	2.1	93.6	3.1	1.0	?
60 hours, - - -	994,000,000	.1	.9	93.2	3.0	2.9	?
72 hours, - - -	687,000,000	.1	1.8	86.0	2.3	9.4	?
84 hours, - - -	420,000,000	.6	2.0	82.3	1.1	14.0	—

\* Too many liquefiers.

TABLE 7.—(Continued.)

EXPERIMENT, DATE AND AGE OF CREAM.	Total number of bacteria per cubic centimeter.	PROPORTION OF DIFFERENT TYPES OF BACTERIA IN THE CREAM.					
		Liquefying bacilli.	N (non-lique- fying bacte- rium).	B. 206.	B. 208.	B. 202.	Miscella- neous.
<i>Experiment No. 5.</i> <i>March 7, 1901.</i>		%	%	%	%	%	%
Fresh, - - -	44,420	8.0	53.0	16.8	9.0	?	13.2
12 hours, - - -	309,000	7.3	34.7	41.0	5.9	?	11.1
24 hours, - - -	14,200,000	11.8	31.4	29.0	12.4	—	15.4
36 hours, - - -	303,000,000	.9	7.6	65.0	17.3	2.0	7.2
48 hours, - - -	1,500,000,000	.1	.5	86.7	5.8	6.6	?
60 hours, - - -	1,344,000,000	—	2.5	88.6	1.3	9.8	?
72 hours, - - -	1,245,000,000	?	?	89.0	?	11.0	?
84 hours, - - -	774,300,000	?	?	89.5	—	10.5	—
<i>Experiment No. 6.</i> <i>May 7, 1901.</i>							
Fresh, - - -	385,000	16.0	22.0	31.2	8.0	—	23.0
12 hours, - - -	4,300,000	11.1	22.0	61.0	2.0	—	3.9
24 hours, - - -	92,000,000	1.0	13.5	58.5	6.4	16.5	5.0
36 hours, - - -	440,000,000	.2	.3	69.0	1.0	29.5	?
48 hours, - - -	551,000,000	?	?	69.0	?	31.0	?
60 hours, - - -	?	?	?	60.0	?	40.0	?
72 hours, - - -	342,000,000	?	?	58.0	?	42.0	?
<i>Experiment No. 7.</i> <i>June 11, 1901.</i>							
Fresh, - - -	36,000,000	.2	29.0	55.0	2.5	—	13.2
12 hours, - - -	406,000,000	?	3.8	76.6	2.3	17.3	?
24 hours, - - -	1,082,000,000	?	1.4	80.9	1.2	16.5	?
36 hours, - - -	1,663,000,000	?	.6	86.1	.5	12.8	?
48 hours, - - -	759,000,000	?	.7	90.9	.4	8.0	—
60 hours, - - -	569,000,000	?	.8	66.5	.8	32.7	—
<i>Experiment No. 8.</i> <i>June 4, 1901.</i>							
Fresh, - - -	150,000	?	40.0	6.6	17.0	—	36.0
12 hours, - - -	3,000,000	Liquefiers prevent determination.					
24 hours, - - -	129,000,000	8.9	?	77.5	—	—	14.4
36 hours, - - -	664,000,000	1.4	?	92.5	1.8	1.9	2.4
48 hours, - - -	861,000,000	.9	?	89.8	1.1	8.2	—
60 hours, - - -	202,000,000	.2	?	80.0	1.1	19.0	—
72 hours, - - -	89,000,000	—	—	68.3	.7	31.4	—
<i>Experiment No. 9.</i> <i>June 11, 1901.</i>							
Fresh, - - -	34,000	8.0	11.0	6.0	?	—	75.0
12 hours, - - -	2,000,000	Liquefiers prevent determination.					
24 hours, - - -	?	Liquefiers prevent determination.					
36 hours, - - -	412,000,000	1.5	2.4	80.0	11.4	—	4.7
48 hours, - - -	914,000,000	1.1	—	86.4	7.8	—	—
60 hours, - - -	782,000,000	.6	—	87.8	7.2	4.6	—
84 hours, - - -	307,000,000	—	—	75.4	2.4	22.2	—

The important facts shown by these tables may be briefly summarized as follows:

1. A small number of bacteria in the cream at the beginning of an experiment indicates that the cream was tolerably fresh. There was, however, considerable variation in the number in different experiments, varying from a number so small as to be impossible to estimate with the dilutions used, up to about thirty-six million in the specimen containing the largest numbers. It should be stated that the different dairies tested showed a tolerably uniform difference in this respect, cream from some dairies having always a small number and that from others a larger number, a fact which was parallel with the care exercised in the handling of the cream at the dairy.

2. There is in all cases a constant and rapid increase in the number of bacteria during the ripening of the cream, continuing for 36 to 48 hours, or sometimes 60 hours. The numbers reached at the time of maximum growth, as will be seen from the tables, are enormous. In the fifth and seventh experiments, for example, within 48 hours there were a billion and a half bacteria per cubic centimeter. It should be here noticed that these numbers are far in excess of anything ever reported elsewhere for natural media. So far as we know the number of bacteria in no other natural medium ever examined by bacteriologists begins to approach the number found in cream ripened for 36 to 48 hours.

3. The number of bacteria present at the maximum is quite independent of the number present at the start. In the second experiment the number at the start was less than two million, but within 48 hours the number was about as great as in any other lot tested. In the first experiment the number at the start was over two million, while the maximum number was only about one-quarter that of experiment No. 2. Some of the other experiments illustrate the same thing perhaps more clearly. The conditions which regulated the number present at the maximum we have as yet been unable to determine.

4. After reaching a maximum in about 48 hours there is a universal decrease in numbers of bacteria. The numbers fall off during the next few hours, and by the 70th hour may have

decreased to a comparatively few millions. This has been universally the case in these experiments. In one or two cases the cream was kept for several days longer and a bacteriological examination made after it was a week old. In these samples the bacteria had nearly all disappeared, a few acid forms alone remaining, and the cream had become a nearly pure culture of the well-known *Oidium lactis*. The explanation of this disappearance of bacteria we are unable to give.

5. In all experiments the number of liquefying bacteria at the start was quite large, but the proportion varied from .2 to 16 per cent. These bacteria apparently increase for a few hours, at least in some of the experiments; but after about 12 hours they decrease in proportion, and in the later periods of ripening become so few as to be incalculable, or disappear entirely. In most of the tests of completely ripened cream no traces of liquefying bacteria were found.

6. The species of bacteria indicated by N. in the third column of the table appears to have a very peculiar relation to the dairies of this vicinity. It is in all cases abundant in the fresh cream, the smallest proportion noted being 11 per cent. and the largest 88 per cent. In every test, however, the proportion of this species of bacteria decreased with the successive plates and became very small in the later periods of ripening. It did not seem to disappear absolutely, for even in the late periods of ripening a few colonies of bacteria N. could be found, but the number was so small as to be inappreciable in the percentages.

7. The group of bacteria which we have here called Miscellaneous, including the several species which do not produce acid nor liquefy gelatin, was in all cases somewhat large at the outset, varying from 5 to 75 per cent., but regularly decreased in numbers and in the late periods of ripening had entirely disappeared.

8. The most characteristic feature of cream ripening consists in the growth of *B. acidi lactici* (206). This characteristic lactic bacillus is found in very small numbers in fresh milk and cream. In other experiments, not recorded here, it has been found that in perfectly fresh milk the number of this species of



bacteria is extremely small; indeed, so few of them are present that they can be found in only a small percentage of the samples of freshly drawn milk. In the cream which we have tested the numbers were at the outset always small, in some cases so few that we could not find them at all with the dilutions which we were obliged to use. In the different samples the proportion was quite variable, but always small. With the successive hours of ripening the number of the bacteria of this species increased with perfect regularity, until at the time when the number of organisms in the cream was at its maximum, the proportion of No. 206 had reached usually about 90 per cent. and sometimes more. This, of course, meant enormous actual numbers, for 90 per cent. of the many millions found is a very large number.

9. The *B. lactis aerogenes* has a peculiar relation to the ripening cream. It is always present in small proportions; it appears neither to increase nor to decrease with any regularity during the ripening, being usually found at the outset in small numbers and at the close of the ripening in similar small numbers. Although the percentage did not regularly increase or decrease, there was a constant slight increase in actual numbers.

10. The lactic bacterium No. 202 appears to be quite characteristic in these dairies. It was rarely found in fresh cream, doubtless because of its small numbers, made its appearance after a few hours, and in practically all cases began to increase somewhat after 36 to 48 hours, being commonly present in larger proportion at the close of the experiments than at the beginning.

11. From these facts it will be seen that in old, well ripened cream we have a nearly pure culture of two species of lactic bacteria, No. 206 and No. 202. The immense numbers given in the first column consisted commonly of over 98 per cent. of these species, the others being quite incidental. It is of course to be noted that the maximum numbers which we have obtained represent cream that was somewhat older than normally ripened cream, but practically the same facts are true of the normally ripened cream, as shown by the previous tables.

From these facts it would at first appear that the ripening of cream is to be attributed wholly to the acid bacteria. Certain it is that these bacteria are the ones which grow most abundantly during the ripening and are present in large proportions at its close. We were at first inclined to believe therefore that the ripening of cream is to be attributed to the lactic organisms alone. Further consideration and some further experiments have led us to doubt this, without leading us yet to any definite conclusion. It will be noticed that during the first few hours of ripening, *i. e.*, during the hours in which the cream is separating from the milk by the gravity method and the twelve hours following, other bacteria than the lactic species have been multiplying. Cream that is twenty-four hours old from the time the milk is drawn from the cow contains a vast proportion of miscellaneous bacteria and only a small number of acid bacteria. It is certain that a considerable part of the cream ripening must have occurred before this time, and that the later ripening of the cream simply completes the process. Up to this time the lactic bacteria have been so few that they could have had little or no effect upon the cream. All of the changes then in the first twelve to twenty hours must be attributed to other bacteria than the acid organisms. Moreover, it will be seen from the tables that, though the *percentage* of miscellaneous bacteria constantly decreases, their *numbers* actually increase for a while. For example, the liquefying bacteria in the fifth experiment were present in the following numbers in the first five tests: 3,500, 21,000, 1,540,000, 2,700,000, 1,500,000. The actual numbers were increasing although the proportion decreased from 8 per cent. to .1 per cent. In one or two experiments on June butter the increase of liquefiers in the first twelve hours was much larger, so great indeed that it was impossible to estimate the number of bacteria on the plates because of the complete liquefaction of the gelatin. These facts of course show that during the first twelve hours of ripening other bacteria than the acid bacteria are multiplying and must produce an influence upon the cream. It would seem, therefore, that the ripening of cream must consist of two phases: the first comprising the first twelve hours or more of ripening and due to the growth of miscellaneous bacteria; the second beginning after twelve hours and

due almost wholly to the growth of lactic bacteria. These considerations lead us to believe that the ripening is not wholly a factor of acid bacteria, but upon this matter we recognize more experimentation is needed.

#### GENERAL SUMMARY.

*We may now give a general summary of the conclusions which were drawn from the long series of experiments above detailed in regard to the actual bacteriological development that occurs during the normal ripening of cream.*

1. *Milk as it is drawn from the cow contains great quantities of bacteria; most of these are miscellaneous forms of liquefying bacteria and other non-acid species. At the outset the number of acid bacteria is very small.*

2. *All species of bacteria increase during the setting of the milk for the separation of the cream.*

3. *For a few hours the alkaline bacteria and the others which have here been included under the head of Miscellaneous increase quite rapidly, while the lactic bacteria are hardly evident.*

4. *After about twelve hours the lactic bacteria have increased so much as to be as numerous as the others, and from this time on they continue to increase with great rapidity until a maximum is reached at about forty-eight hours; after this the numbers gradually decrease and they finally practically disappear.*

5. *The ripened cream contains prodigious numbers of bacteria, larger numbers than are known in any other natural medium. They are, however, nearly all lactic bacteria.*

6. *After the first twelve hours all species of bacteria except the two lactic species decrease in relative numbers and finally absolutely disappear.*

7. *The two common species, Nos. 206 and 202, increase regularly from the beginning of an experiment until the maximum. No. 208 is always present in considerable quantity and during the ripening increases in numbers though not increasing in proportion.*

8. *The cream which is received by a creamery is already partly ripened, as indicated by the immense numbers of bacteria it contains. All of the changes which occur in the cream under the*



*influence of the miscellaneous bacteria have already occurred, and the ripening that takes place in the creamery is due wholly, or almost wholly, to the growth of the acid bacteria.*

9. *A ripened cream is almost a pure culture of acid bacteria, but this does not mean that the ripening has been produced by these acid bacteria alone.*

10. *That the lactic bacteria play an important part in the ripening is perfectly evident; that they are the sole cause of the changes occurring in the ripening is not so evident.*

11. *The peculiar flavor of June butter, which is so much desired by the butter maker, is not due to the development of the common lactic bacteria. Butter ripened during the winter months develops the two species of lactic bacteria as abundantly and as quickly as does that ripened in June, but the flavor does not make its appearance. In the last three experiments recorded the June flavor was very noticeable in the cream, but the development of the acid bacteria, or the two species referred to, was practically the same as in all of the previous experiments. The June flavor, therefore, cannot be due to these common lactic bacteria.*

12. *To what this June flavor is due we are not as yet satisfied. Whether it will prove to be due to the large growth of miscellaneous bacteria during the first few hours of ripening, or whether it is due to a difference in the chemical nature of the cream remains for further experiments to decide.*

## FIELD EXPERIMENTS WITH FERTILIZERS.

BY C. S. PHELPS.

Two classes of field experiments with fertilizers, one known as "soil tests" and the other as "special nitrogen" experiments, were undertaken by the Station soon after its organization in 1888, and have been continued until the present. The policy has been to repeat these experiments with the same fertilizers on the same plots year after year, in the belief that the results would thus continually increase in value. Other field experiments have also been added at different times since these were begun. Those now in progress include the following:

1. Special nitrogen experiments on corn, cow peas, and soy beans, for the purpose of studying the effects of nitrogen in different quantities and combinations in the fertilizers upon the yields and the composition of the crops.
2. A rotation soil test on the Station land, for the purpose of studying the deficiencies of the soil and the needs of different crops for the different ingredients of fertilizers.
3. Experiments with grasses and other forage crops, mainly for the purpose of comparing the feeding values of different fodder crops, and of studying the effects of the nitrogen in the fertilizers upon the proportion and amount of protein in the different crops.
4. An experiment on soil improvement, for the purpose of comparing the relative economy of (1) stable manure, (2) a "complete" chemical fertilizer, and (3) green manures alone and in connection with mineral fertilizers for improving a soil apparently deficient in organic matter and in available nitrogen.

Detailed results of investigations of each year have been published in the annual reports of the Station; and from time to time summaries of the results of the experiments of several

years have been given.\* The present account of the experiments of 1900 is designed as a brief report of progress. The experiments of the first and second classes mentioned above are described in the present article, and those of the fourth class in the article succeeding this. Those of the third class will probably be given in a future Report.

#### SPECIAL NITROGEN EXPERIMENTS.

The special nitrogen experiments on corn, cow peas and soy beans conducted by the Station in preceding years were continued during 1900. The purpose of these experiments is to study the effect of nitrogenous fertilizers upon the yields and composition of the crops. The plan of the experiments has been described in detail in former reports.† It consists, briefly, in growing the crops on a series of plots treated with mineral fertilizers supplying phosphoric acid and potash in definite amounts, and nitrogenous fertilizers supplying nitrogen in different amounts, and comparing the weights and analyses of the crops from the different plots. The diagram on the next page and the discussion following it illustrate the methods of the experiment.

The field used for the experiments is divided into ten long, narrow, parallel plots. These are indicated by the numbers 0, 7, 8, etc., at the north and south ends of the plots. The plots numbered 0 and 00 receive no fertilizer. Plots 6*a* and 6*b* receive dissolved bone-black at the rate of 320 pounds, with 53 pounds of phosphoric acid per acre, and muriate of potash at the rate of 160 pounds, with 82 pounds of potash per acre, this mixture being called for convenience "mixed minerals." Plots 7, 8 and 9 receive in addition to the minerals respectively 160, 320 and 480 pounds of nitrate of soda, with 25, 50 and 75 pounds of nitrogen per acre, while plots 10, 11 and 12 receive in addition to the mixed minerals respectively 160, 320 and 480 pounds of sulphate of ammonia, with 25, 50 and 75 pounds of nitrogen per acre. The adjoining plots are separated from each other by narrow strips that are not fertilized.

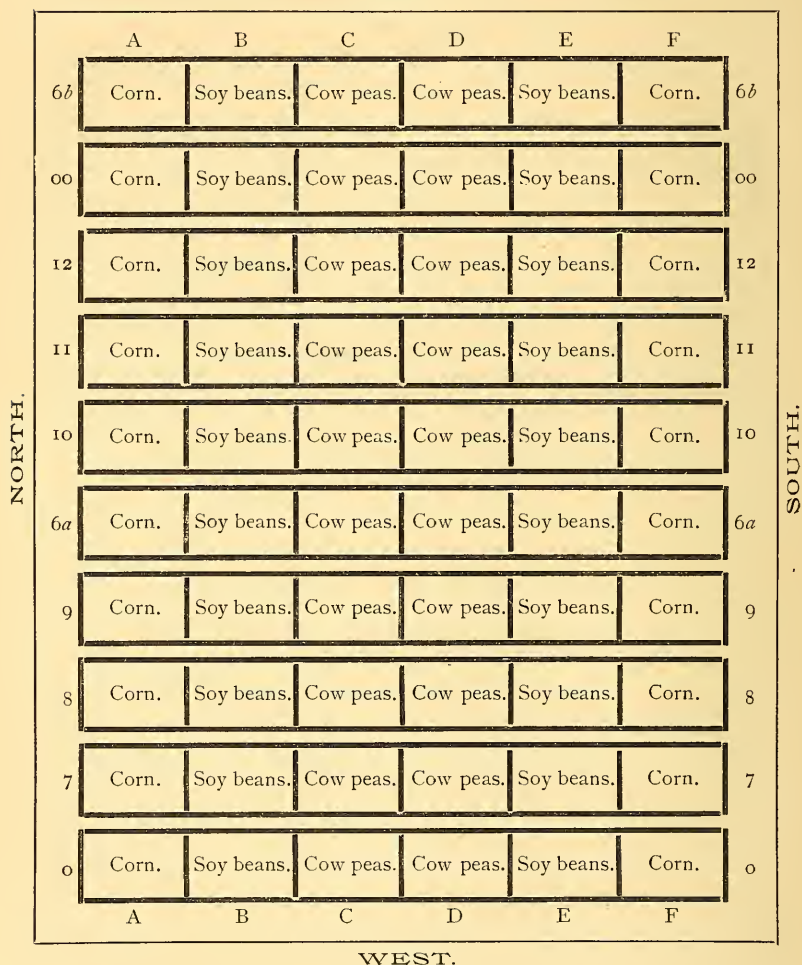
\* See especially Reports for 1898 and 1899.

† *Idem.*

*Diagram illustrating the arrangement of the plots, the method of dividing the plots into sections, and the kind of crop planted on each section.*

The plots are indicated by numbers, the sections by letters.

EAST.



As shown in the diagram, each plot is sub-divided into six one-fiftieth acre sections, indicated by the letters A to F beside the sections on plots 0 and 6b. It is generally understood that the effects of fertilizers on the yields of crops cannot be determined as accurately on the small sections as they might

be on the larger plots. The most important part of these experiments, however, is believed to be the study of the effects of nitrogen applied in the fertilizers upon the proportions of nitrogenous compounds (protein) produced in the crops. The smaller sections give results bearing on this question that are probably quite as accurate as would be obtained by the use of larger plots. The advantages in sub-dividing the larger plots into sections and growing the same crop on different series of sections is that the probability of differences due to irregularities of the soil is to a certain extent eliminated; and as a larger number of crops can be grown in the same experiments, the results thus have a wider application.

The name of the crop grown in each section is given in the space by which the section is indicated in the above diagram. Two series of sections, A and F, were planted with corn; two series, B and E, with soy beans, and two series, C and D, with cow peas. In the tables and discussions on the following pages, the results with the soy beans on the two series of sections have been combined just as though a single series of one-twenty-fifth acre sections were used. The same is true of the results with cow peas. In the case of the corn, however, the results on the two series have been kept separate since, as will be explained later, the methods of fertilizing were not strictly uniform on both series, lime having been applied in 1898 to series A at the north end of the field, while series F at the south end did not receive the lime in addition to the regular fertilizer.

As a whole the results of the experiments of 1900 were fairly normal. The weather conditions were generally favorable and the yields of crop were fair. It is noticeable, however, that the yields are not as heavy as those obtained in the experiments of 1895 and 1896. This may be due to the fact that the plots on which the crops are grown have received only commercial fertilizers for eleven years. It is possible that the organic matter (humus) in the soil has been gradually reduced, and the yields have consequently fallen off. This can perhaps be accounted for by the assumption that in seasons of heavy rains the lack of humus in the soil would tend to favor the leaching of the soluble nitrogen compounds into the subsoil and perhaps beyond the reach of the crops; while in dry



seasons the crops would suffer more for lack of moisture where relatively small amounts of humus were present in the soil.

*Explanation of tables.*—Two tables of data are given in connection with the discussion of the results for each crop. The first table in each case gives the weight and cost of fertilizers per acre, the weights of crop per section and the calculated yields per acre, and the increase of the yield from the sections with fertilizers over that from the sections without fertilizer. The yields per section are the weights of the green crop taken in the field when harvested, or the weight of the crop taken when partially dried. The cow peas (vines) were weighed as soon as possible after cutting. The total corn (grain) and the soy bean seed from each section were dried in the barn and weighed when thought to be in good condition for grinding into meal. The corn stover was cured in the field and then weighed, while the soy bean straw was discarded because the leaves practically all fall off before the seed has fully ripened.

The costs of the fertilizers per acre given in the tables represent only the market price of the various ingredients of the fertilizers used in the experiments. The cost of mixing the materials, of transportation, etc., is not included. The costs are calculated from the weights of the ingredients per acre and the values of the ingredients as adopted by the New England Experiment Stations. These values vary from year to year. The valuation of the different ingredients used in the experiments of 1900 were as follows:

	Per Pound.
Nitrogen as nitrate of soda, - - - - -	14 cts.
Nitrogen as sulphate of ammonia, - - - - -	16½ "
Organic nitrogen (in dried blood), - - - - -	16 "
Phosphoric acid (soluble), - - - - -	5 "
Potash as muriate, - - - - -	4½ "

The second table in each case gives the total yields of the crop per acre, the percentages of water-free substances or of dry matter in the crop when weighed for the determination of the yields, the percentages of protein ( $N. \times 6.25$ ) in the dry matter and the estimated yields of dry matter and of protein per acre.

The amounts of dry matter per acre are calculated by multiplying the total weight of crop as harvested by the percentage

of dry matter, and the amounts of protein per acre are calculated by multiplying the estimated weight of dry matter in the crop by its percentage of protein. The last two columns of the table show the percentages of the yields of dry matter and of protein for each section if the average of the yields from the mineral plots be taken as a basis (100).

*Protein. Proteid and non-proteid nitrogen.*—It is customary to estimate the protein in plant tissues by multiplying the total nitrogen by the factor 6.25. The reason for this is that a large number of the compounds which are called albuminoids or proteids contain not far from 16 per cent. of nitrogen. But later research is emphasizing more and more clearly that (1) the true albuminoids or proteids which are used as food for building the nitrogenous tissues and other materials of the body often contain more and occasionally less than 16 per cent.; (2) in the growing parts of the plant especially, more or less of the nitrogen is in the form of so-called amids, like asparagin, which have not the nutritive value of the true albuminoids or proteids; and (3) in some cases a not inconsiderable part of the nitrogen in the plant may be in the form of nitric acid, which has no value as food for animals.

Unfortunately the chemical methods thus far devised for determining the amounts of amids and other like non-proteid or non-albuminoid nitrogenous compounds do not give satisfactory results. In making the analyses of the samples of these crops tests for nitrates were made in a considerable number of samples, especially in those from sections of the plots upon which the larger quantities of nitrogen were used in the fertilizer. The object of these tests was to ascertain if any appreciable amount of the nitrogen of the fertilizer was taken up by the plant and held in its tissues in the form of nitrates without being transformed into organic nitrogen compounds. These nitrates would have no food value. The tests were made by treating cold water extracts of the samples with a sulphuric acid solution of di-phenylamin. Only very small traces of nitrates were found in any of the tests, indicating that practically all of the nitrogen of the fertilizer taken up by the plant was transformed into organic nitrogen compounds.

Although the factor 6.25 used for estimating the amount of protein in the crop from the quantity of nitrogen as determined by analysis is known not to be entirely correct, still for practical purposes it is perhaps sufficiently accurate; and in order to make the results of these experiments readily comparable with those of preceding years as published, it seems best to make use of the same factor that has been used in the past.

#### EXPERIMENTS WITH CORN.

As shown in the diagram on page 36, corn is grown on the two series of sections lettered A and F at the north and south ends of the plots. The same kind of corn, a Rhode Island White Cap, is grown on both series. The seed planted on each section in any year is that grown on the same section during the preceding year. The original seed planted on series F was obtained at the beginning of the experiments in 1895. For series A a new lot of seed was obtained in 1898.

Previous to 1898 both series of corn sections, A and F, were fertilized in the same manner. It was observed, however, that the corn did not appear to grow so well on some of the sections of plots treated with the largest quantities of sulphate of ammonia as on those treated with the corresponding amounts of nitrate of soda. The question arose whether the soil on the former plots might not become acid to such a degree as to be unfavorable to the growth of corn. The natural tendency is for the ammonia of the sulphate to be changed in the soil into nitrous and nitric acids, which are either taken up by the plants or leached out of the soil in drainage waters. In the nitrate of soda, on the other hand, the nitrogen is in the form of nitric acid, which is in like manner removed from the soil by the plants and in drainage waters. Thus on the sulphate plots the sulphuric acid and on the nitrate plots the soda would be left as residues in the soil, to be slowly removed by the plants or in drainage waters, and would thus tend to accumulate. In such a case, the hypothesis that the soil on the sulphate plots, especially where large quantities of the material were used, might become so acid as to interfere with the growth of corn, would seem to be reasonable.

The acidity of the soil on these sulphate plots might be corrected by lime, in which case there would be a tendency toward

improvement in growth. To get light upon this question it was decided to apply lime to one series of sections and not to the other. In the experiments of 1898, therefore, the plots were treated with the nitrogenous and mineral fertilizers as explained in a preceding paragraph, and in addition 40 pounds of air-slacked lime (2,000 pounds per acre) was applied on each section in the series A at the north ends of the plots, but no lime was applied on series F at the south ends. No extra lime has been applied since then, as it was believed the action of the lime would continue for several years. For this reason the results of the experiments on the two series of corn sections are reported separately. A comparison of the yields on the sections with and without lime is given below in the discussion of Tables 8 and 9.

TABLE 8.

SPECIAL NITROGEN EXPERIMENT ON WHITE FLINT CORN  
(SERIES A).

*Weight and cost of fertilizers per acre, total crop, and increase of crop over that of nothing plots.*

No. of Plot.	FERTILIZERS PER ACRE.			YIELD PER SECTION (1.50 Acre).		ESTIMATED YIELD PER ACRE.		Gain over nothing plots.
	Kind.	Weight.	Cost.	Shelled Corn.	Stover.	Shelled Corn.	Stover.	
		Lbs.	\$	Lbs.	Lbs.	Bu.	Lbs.	Bu.
0	Nothing, - - - -	—	—	19.8	26.3	17.6	1315	—
7	{ Mixed Minerals, as No. 6a, 480 } { Nitrate of Soda (25 lbs. N.), 160 }	480 } 160 }	9.64	42.5	42.3	37.9	2115	16.4
8	{ Mixed Minerals, as No. 6a, 480 } { Nitrate of Soda (50 lbs. N.), 320 }	480 } 320 }	13.14	62.0	46.0	55.3	2300	33.8
9	{ Mixed Minerals, as No. 6a, 480 } { Nitrate of Soda (75 lbs. N.), 480 }	480 } 480 }	16.64	64.0	46.5	57.1	2325	35.6
6a	{ Dis. Bone-black, { Mixed { Mur. of Potash, { Min'ls, { 160 }	320 } 160 }	6.14	29.0	41.0	25.9	2050	4.4
10	{ Mixed Minerals, as No. 6a, 480 } { Sulph. of Am. (25 lbs. N.), 120 }	480 } 120 }	10.27	51.0	47.8	45.5	2390	24.0
11	{ Mixed Minerals, as No. 6a, 480 } { Sulph. of Am. (50 lbs. N.), 240 }	480 } 240 }	14.39	61.0	55.8	54.4	2790	32.9
12	{ Mixed Minerals, as No. 6a, 480 } { Sulph. of Am. (75 lbs. N.), 360 }	480 } 360 }	18.52	66.0	53.5	58.9	2675	37.4
00	Nothing, - - - -	—	—	28.5	30.8	25.4	1540	—
6b	Mixed Minerals, as No. 6a, 480	480	6.14	37.0	45.3	33.0	2265	11.5



TABLE 9.

SPECIAL NITROGEN EXPERIMENTS ON WHITE FLINT CORN  
(SERIES F).*Weight and cost of fertilizers per acre, total crop, and increase of  
crop over that of the nothing plots.*

No. of Plot.	FERTILIZERS PER ACRE.			YIELD PER SECTION (1-50 Acre).		ESTIMATED YIELD PER ACRE.		Gain over nothing plots.
	Kind.	Weight.	Cost.	Shelled Corn.	Stover.	Shelled Corn.	Stover.	
		Lbs.	\$	Lbs.	Lbs.	Bu.	Lbs.	Bu.
o	Nothing, - - - -	—	—	14.8	22.3	13.2	1115	—
7	{ Mixed Minerals, as No. 6a, 480 } { Nitrate of Soda (25 lbs. N.), 160 }	640	9.64	36.5	40.3	32.6	2015	17.3
8	{ Mixed Minerals, as No. 6a, 480 } { Nitrate of Soda (50 lbs. N.), 320 }	800	13.14	53.5	41.5	47.7	2075	32.4
9	{ Mixed Minerals, as No. 6a, 480 } { Nitrate of Soda (75 lbs. N.), 480 }	960	16.64	52.3	25.8	46.7	1290	31.4
6a	{ Dis. Bone-black, { Mixed } { Mur. of Potash, { Min'ls, } 160 }	320	6.14	32.0	32.3	28.5	1615	13.2
10	{ Mixed Minerals, as No. 6a, 480 } { Sulph. of Am. (25 lbs. N.), 120 }	600	10.27	52.5	41.3	46.8	2065	31.5
11	{ Mixed Minerals, as No. 6a, 480 } { Sulph. of Am. (50 lbs. N.), 240 }	720	14.39	59.5	37.5	53.1	1875	37.8
12	{ Mixed Minerals, as No. 6a, 480 } { Sulph. of Am. (75 lbs. N.), 360 }	840	18.52	46.5	32.5	41.5	1625	26.2
oo	Nothing, - - - -	—	—	19.5	19.0	17.4	950	—
6b	Mixed Minerals, as No. 6a, 480	480	6.14	40.0	37.5	35.7	1875	20.4

*The amounts of nitrogen in the fertilizer and the total yields of crop.*—Tables 8 and 9 above show the kinds, quantities and costs of fertilizers per acre as used on the different plots, the yields of corn and stover per section and per acre, and the increase in yields of grain on the fertilized sections over the average of the yields obtained on the two sections where no fertilizers were used. The yields from the sections of series A are given in Table 8 and those from the sections of series F in Table 9. The yields per section are the actual weighings of the crop, and the yields per acre are calculated from these and the size of the sections. The last column of the table shows the effects of the different fertilizers on the yields of grain by a comparison of the yield per acre obtained on the sections fertilized with the average of the yield from the sections of the two plots not fertilized.

The yields on the sections of plots o and oo, which were not fertilized, were of course very light. This is no doubt due to



the fact that these plots have received no fertilizers for the past twelve years. The yields on the sections of plots 6*a* and 6*b*, on which mineral fertilizers only were applied, were much better than on the sections not fertilized, and perhaps better than might be expected considering the fact that no nitrogen has been used with the mineral fertilizers on these plots since 1890. The results on the sections of plot 6*b* were considerably better than those on plot 6*a*. The lack of nitrogen in the soil of the sections supplied with only mineral fertilizers seemed to have caused a pale color in the crop during the growing season, and much smaller yields of grain, with considerably less stover. On the whole, however, the mineral fertilizers alone appear to give better results in these experiments with corn than has been obtained in similar experiments with common grasses. This would seem to indicate that corn is better able than the grasses to gather nitrogen from natural sources.

The yields obtained on the sections of plots 7 and 10, to which the smallest rations of nitrogen (25 pounds per acre) were applied, were considerably larger, especially on series A, than the yields obtained where only mineral fertilizers were used. The increase on plot 10 is somewhat greater than that on plot 7. This difference is doubtless due in part at least to the fact that in heavy rains the soil on plot 7 becomes washed so that the conditions for growth are less favorable than on the other plots. On the sections of plots 8 and 11, where 50 pounds of nitrogen per acre was used, there was quite an increase in the yields over those obtained from the use of either mineral fertilizers only or minerals plus the small ration of nitrogen. The yield of crop from the sections of plots 9 and 12, on which 75 pounds of nitrogen per acre were used, was slightly greater on series A than was obtained from sections where 50 pounds of nitrogen was used, but in the case of the corresponding sections on series F there was no increase. In fact there was a falling off in yield on section F of plot 12 as compared with section F of plot 8. This condition can probably be accounted for by assuming that the soil on section F of plot 12 had become so acid as to interfere with the growth of corn. This is explained below in the discussion of the yields with and without lime.

The relatively small increase in yield from the large ration of nitrogen as compared with that from the medium and small

rations would seem to indicate that corn is not able to utilize profitably large amounts of nitrogen from soluble fertilizers such as nitrate of soda and sulphate of ammonia. Many experiments made in past years by this Station have shown that 50 pounds of nitrogen per acre from fertilizers like those mentioned above is about as much as can profitably be used on corn. Better results might very likely come from the use of stable manures supplying equally large quantities of nitrogen than from the same quantities of nitrogen in the form of nitrate of soda or of sulphate of ammonia. The stable manures have a value outside of their nitrogen content which is not found in the chemical fertilizers.

*Comparison of yields with and without lime.*—As pointed out above, the yield from section F of plot 12 was less than that from section F of plot 11, while that from section F of plot 9 was practically the same as from section F of plot 8. The method of fertilizing plots 8 and 9 is the same as that for plots 11 and 12 respectively, except that nitrate of soda is used on the former, and sulphate of ammonia on the latter. The difference in yield between plots 8 and 9 might be expected therefore to correspond somewhat to that between plots 11 and 12, provided the fertilizers used had like beneficial action on the growth of the crops. Such, however, has not been the case, as will be seen from the following table, which gives the average of the yields for the past three years from the two series of sections on both the nitrate of soda and the sulphate of ammonia plots.

*Comparison of average yields of corn and stover from sections with and without lime.*

FERTILIZER.	Plot No.	AVERAGE YIELDS PER ACRE.			
		Series F, without lime.		Series A, with lime.	
		Shelled corn.	Stover.	Shelled corn.	Stover.
		Bu.	Lbs.	Bu.	Lbs.
Nitrate of Soda group, {	7	30.0	2015	39.4	2420
	8	44.2	2345	53.5	2770
	9	44.6	1990	53.7	2560
Sulphate of Ammonia group, {	10	42.2	2325	47.6	2755
	11	46.7	2250	50.3	3325
	12	37.8	1870	53.9	2690

Thus it will be seen that on the sections without lime the average yield of shelled corn per acre was 44.2 bushels from plot 8 and 44.6 bushels from plot 9, while it was 46.7 bushels from plot 11 and 37.8 bushels from plot 12.

To explain this decrease in yield from plot 12 it was assumed that on this plot on which the large amounts of sulphate of ammonia were used the acidity of the soil resulting from the accumulation of sulphuric acid residue became so great as to interfere with the growth of the corn. As already explained, lime was applied to correct this acidity. In the table above it will be seen that on the sections with lime the average yield of shelled corn per acre was 53.5 bushels from plot 8 and 53.7 bushels from plot 9, while it was 50.3 bushels from plot 11 and 53.9 bushels from plot 12.

It will be noticed that the average yields from all the plots of both the nitrate of soda and the sulphate of ammonia groups was larger from the sections with lime than from those without it. This would seem to indicate that lime had some directly beneficial effect upon the fertility of the soil; possibly such as aiding in the nitrification of nitrogen compounds present in the soil.

The experimental results apparently favor the hypothesis that the soil on the plot with the large quantity of sulphate of ammonia had become injuriously acid, and that the acidity was corrected by lime. The attested fact is that the yields were greater from all the plots in both groups, but that the lime had the greatest influence on the yield from the plot with the largest ration of the sulphate.

*The amounts of nitrogen in the fertilizer and the proportions of protein in the crop.*—Tables 10 and 11 illustrate the effects of the nitrogen of the fertilizers upon the composition of the plant as determined by chemical analysis. They are intended especially to show the increase in the proportion of nitrogen and thus of protein in the crop following an increase in the proportion of nitrogen in the fertilizer. The data included in these tables are the weights of the crop per section as harvested, and the percentages and calculated weights of dry matter and of protein per acre. In the last two columns of the table the yields of dry matter and of protein per acre are given in

percentages of the average of the yields from the two mineral plots. This comparison of results obtained on the sections having mineral fertilizers only with the results obtained on sections having different quantities of nitrogen in addition to the mineral fertilizers serves to show the relative increase of dry matter and of protein which follows the use of nitrogen in the fertilizer.

In the discussion of results it seems best to omit the consideration of those obtained on the sections to which no fertilizer was applied, as they are apparently abnormal, the proportion of protein in the crops being in some cases higher than that in the crops grown with considerable quantities of nitrogenous fertilizers. This same thing has been observed in previous experiments, and is explained in former Reports\* as probably due to the fact that in the grain grown without fertilizers there is a large proportion of "poor" or "soft" kernels. These latter have been shown by analysis to contain a larger percentage of protein than is found in matured corn, owing possibly to an incomplete development of starch and oil in the immature seeds. In the crop from the sections supplied with mineral fertilizers only, the percentages of protein in the grain and in the stover were less in nearly all cases than in the crop obtained from those sections supplied with nitrogen. It will be noticed, too, that the percentages of protein in the grain and in the stover from the mineral sections were quite uniform for the same series of sections. This would seem to indicate that the conditions of soil were quite uniform on the sections to which the mineral fertilizers only were applied. In the case of the sections supplied with nitrogen in addition to the minerals the percentages of protein increase gradually (with one exception, section A, plot 12) with the increase in the quantities of nitrogen used. This accords quite well with the results obtained in similar experiments in previous years, and shows that, up to a certain limit at least, the proportion of protein in the grain and in the stover tends to increase with the amounts of nitrogen used in the fertilizer.

\* See p. 28 of the Report of this Station for 1890; also p. 136 of the Report for 1898.



TABLE 10.

SPECIAL NITROGEN EXPERIMENTS ON WHITE FLINT CORN  
(SERIES A).*Percentages and pounds per acre of dry matter and of protein in the grain and stover.*

No. of Plot.	FERTILIZERS PER ACRE.		Portion of crop.	Weight at harvest, per acre.		Dry matter.		Protein in dry matter. N. $\times$ 6.25.		Percentage of yield on basis of yield from min'ral plots.	
	Kind.	Weight.		Lbs.	%	Lbs.	%	Lbs.	%	Dry matter.	Protein.
0	Nothing, - - - -	Lbs. —	Grain, Stover, Total,	990 1315 2305	90.8 86.9 —	899 1143 2042	6.94 7.31 —	89 84 173	61 66 64	63 90 74	
7	{ Mixed Minerals, as No. 6a, { Nitrate of Soda (25 lbs. N.),	480 160	Grain, Stover, Total,	2125 2115 4240	90.0 78.8 —	1913 1667 3580	9.81 5.56 —	188 93 281	130 96 112	132 100 120	
8	{ Mixed Minerals, as No. 6a, { Nitrate of Soda (50 lbs. N.),	480 320	Grain, Stover, Total,	3100 2300 5400	91.2 80.0 —	2827 1840 4667	11.56 6.19 —	327 114 441	192 107 146	230 123 188	
9	{ Mixed Minerals, as No. 6a, { Nitrate of Soda (75 lbs. N.),	480 480	Grain, Stover, Total,	3200 2325 5525	90.4 75.3 —	2893 1751 4644	12.13 7.63 —	351 134 485	196 102 145	247 144 207	
6a	{ Dis. Bone-black, } Mixed { { Mur. of Potash, } Min'ls, {	320 160	Grain, Stover, Total,	1450 2050 3500	89.2 77.8 —	1293 1595 2888	9.50 5.75 —	123 92 215	* * *	* * *	
10	{ Mixed Minerals, as No. 6a, { Sulph. of Am. (25 lbs. N.),	480 120	Grain, Stover, Total,	2550 2390 4940	91.3 74.3 —	2328 1776 4104	10.25 4.88 —	239 87 326	158 103 128	168 94 139	
11	{ Mixed Minerals, as No. 6a, { Sulph. of Am. (50 lbs. N.),	480 240	Grain, Stover, Total,	3050 2790 5840	89.3 70.0 —	2724 1953 4677	10.94 5.69 —	298 111 409	185 113 146	210 119 174	
12	{ Mixed Minerals, as No. 6a, { Sulph. of Am. (75 lbs. N.),	480 360	Grain, Stover, Total,	3300 2675 5975	88.5 75.1 —	2921 2009 4930	10.63 6.13 —	311 123 434	198 117 154	212 132 185	
00	Nothing, - - - -	—	Grain, Stover, Total,	1425 1540 2965	93.6 85.1 —	1334 1311 2645	11.44 8.75 —	153 115 268	91 76 83	108 124 114	
6b	Mixed Minerals, as No. 6a,	480	Grain, Stover, Total,	1850 2265 4115	89.3 81.8 —	1652 1853 3505	9.69 5.06 —	160 94 254	* * *	* * *	

\* The average of the yields on plots 6a and 6b is here taken at 100 for comparison.



TABLE 11.

SPECIAL NITROGEN EXPERIMENTS ON WHITE FLINT CORN  
(SERIES F)*Percentages and pounds per acre of dry matter and of protein in the grain and stover.*

No. of Plots.	FERTILIZERS PER ACRE.		Portion of crop.	Weight at harvest, per acre.		Dry matter.		Protein in dry matter, N. $\times$ 6.25.		Percentage of yield on basis of yield from min'ral plots.	
	Kind.	Weight.								Dry matter.	Protein.
		Lbs.		Lbs.	%	Lbs.	%	Lbs.	%		
0	Nothing, - - - -	—	{ Grain, 740	89.9	665	10.69	71	42	44		
			{ Stover, 1115	85.0	948	6.75	64	64	74		
			{ Total, 1855	—	1613	—	135	53	55		
7	{ Mixed Minerals, as No. 6a,	480	{ Grain, 1825	90.4	1650	10.38	171	104	107		
	{ Nitrate of Soda (25 lbs. N.),	160	{ Stover, 2015	84.4	1701	5.50	94	115	108		
			{ Total, 3840	—	3351	—	265	109	107		
8	{ Mixed Minerals, as No. 6a,	480	{ Grain, 2675	92.7	2480	10.81	268	156	174		
	{ Nitrate of Soda (50 lbs. N.),	520	{ Stover, 2075	82.9	1720	7.00	120	116	138		
			{ Total, 4750	—	4200	—	388	137	157		
9	{ Mixed Minerals, as No. 6a,	480	{ Grain, 2615	90.2	2359	11.69	276	149	173		
	{ Nitrate of Soda (75 lbs. N.),	480	{ Stover, 1290	80.3	1036	8.50	88	70	101		
			{ Total, 3905	—	3395	—	364	111	147		
6a	{ Dis. Bone-black, } Mixed {	320	{ Grain, 1600	88.8	1421	9.94	141	*	*		
	{ Mur. of Potash, } Min'ls. {	160	{ Stover, 1615	83.6	1350	5.75	78	*	*		
			{ Total, 3215	—	2771	—	219	*	*		
10	{ Mixed Minerals, as No. 6a,	480	{ Grain, 2625	89.9	2360	10.06	237	149	148		
	{ Sulph. of Am. (25 lbs. N.),	120	{ Stover, 2065	83.3	1720	6.13	105	116	121		
			{ Total, 4690	—	4080	—	342	132	139		
11	{ Mixed Minerals, as No. 6a,	480	{ Grain, 2975	90.5	2692	10.94	295	170	184		
	{ Sulph. of Am. (50 lbs. N.),	240	{ Stover, 1875	84.3	1581	9.56	151	106	174		
			{ Total, 4850	—	4273	—	446	139	181		
12	{ Mixed Minerals, as No. 6a,	480	{ Grain, 2325	90.7	2109	11.25	237	133	148		
	{ Sulph. of Am. (75 lbs. N.),	360	{ Stover, 1625	75.5	1227	10.25	126	83	145		
			{ Total, 3950	—	3336	—	363	109	147		
00	Nothing, - - - -	—	{ Grain, 975	88.4	862	10.44	90	54	56		
			{ Stover, 950	88.7	843	8.37	71	57	82		
			{ Total, 1925	—	1705	—	161	56	66		
6b	Mixed Minerals, as No. 6a,	480	{ Grain, 2000	87.6	1752	10.19	179	*	*		
			{ Stover, 1875	86.4	1620	5.88	95	*	*		
			{ Total, 3875	—	3372	—	274	*	*		

\* The average of the yields on plots 6a and 6b is here taken as 100 for comparison.

It will be noticed from Tables 10 and 11 that the amounts of both dry matter and protein in the crop increased as the amounts of nitrogen in the fertilizers increased, but that the increase in the yield of protein was relatively larger than the increase in the yield of dry matter. This is shown especially in the last two columns of the tables, which compare by percentages the yields of dry matter and of protein from the different sections supplied with nitrogen with the average of the yields from the two sections having the mineral fertilizers only, the latter being taken as a basis (100). These figures bring out clearly the fact that the increase in the amount of protein in the crop following the use of nitrogenous fertilizers is due not only to an increase in the total yields of the crop, but also to an increase in the proportion of protein in the crops from the plots upon which the larger quantities of nitrogen were used, showing that the nitrogen in the fertilizer had a relatively greater tendency to increase the proportion of protein in the crop than it had to increase the total yield of dry matter.

#### EXPERIMENTS WITH COW PEAS.

From the diagram on page 36 it may be seen that the two adjoining series of sections, C and D, were used for the experiments with cow peas. Each section contains one-fiftieth of an acre, but the results obtained on the two series have been combined, and are given in the following tables as if one series of sections of one-twenty-fifth acre each was used. The Clay variety of cow peas has been used for several years. The seed is obtained from the South each year. Most varieties of cow peas do not ripen their seed in this climate. The crop is harvested before or at the time of blossoming, and is used for fodder.

The amounts and costs of the fertilizers per acre, the yields of crop per section as harvested, and the calculated yields per acre are given in Table 12. The percentages and amounts of dry matter in the crop as harvested and the percentages and amounts of protein in the dry matter are given in Table 13.

*The amounts of nitrogen in the fertilizer and the total yields of the crop.*—The effects of the nitrogen of the fertilizer on the total yields of crop are indicated by the results given in Table 12. From the figures in this table it will be seen that the yields

of green crop at harvest are about twice as great on the sections supplied with only mineral fertilizers as on those on which no fertilizer was applied. The average of the yields on the two sections supplied with mineral fertilizers only was practically the same as the average of the yields from all of the plots to which nitrogen was added with the minerals. In this experiment there was some increase in yield where the larger quantities of nitrogen were used in the fertilizers, but not at all in proportion to the increase of nitrogen used. In nearly all of our experiments with this crop covering a period of twelve years there has been very little relation between the yields of the crop and the quantities of nitrogen used in the fertilizer.

TABLE 12.

SPECIAL NITROGEN EXPERIMENTS ON COW PEA FODDER.

*Weight and cost of fertilizers per acre, total crop, and increase of crop over that of the nothing plots.*

No. of Plot.	FERTILIZERS PER ACRE.			Yield per section (1-25 acre).	Estimated yield per acre as harvested.		Gain over nothing plots.
	Kind.	Weight.	Cost.				
		Lbs.	\$	Lbs.	Lbs.	Tons.	Lbs.
0	Nothing, - - - -	—	—	345	8,625	4.3	—
7	{ Mixed Minerals, as No. 6a, -	480	9.64	600	15,000	7.5	6,500
	{ Nitrate of Soda (25 lbs. N.), -	160					
8	{ Mixed Minerals, as No. 6a, -	480	13.14	586	14,650	7.3	6,150
	{ Nitrate of Soda (50 lbs. N.), -	320					
9	{ Mixed Minerals, as No. 6a, -	480	16.64	650	16,250	8.1	7,750
	{ Nitrate of Soda (75 lbs. N.), -	480					
6a	{ Dis. Bone-black, } Mixed {	320	6.14	665	16,625	8.3	8,125
	{ Mur. of Potash, } Minerals. {	160					
10	{ Mixed Minerals, as No. 6a, -	480	10.27	670	16,750	8.4	8,250
	{ Sulph. of Am. (25 lbs. N.), -	120					
11	{ Mixed Minerals, as No. 6a, -	480	14.39	760	19,000	9.5	10,500
	{ Sulph. of Am. (50 lbs. N.), -	240					
12	{ Mixed Minerals, as No. 6a, -	480	18.52	810	20,250	10.1	11,750
	{ Sulph. of Am. (75 lbs. N.), -	360					
00	Nothing, - - - -	—	—	335	8,375	4.2	—
6b	Mixed Minerals, as No. 6a, -	480	6 14	705	17,625	8.8	9,125

For some reason not accounted for, the yield of cow pea fodder in 1900 was larger on the series of sections on which sulphate of ammonia was applied than on the corresponding sections on which nitrate of soda was applied. This was not so in the

experiments of previous years. On the whole the experiments with cow peas seem to indicate that as far as the yields of the crop are concerned good results are obtained from the use of mineral fertilizers, but that nitrogen in addition to the minerals has very little effect upon the yields.

TABLE 13.

## SPECIAL NITROGEN EXPERIMENTS ON COW PEA FODDER.

*Percentages and pounds per acre of dry matter and of protein.*

No. of Plot.	FERTILIZERS PER ACRE.		Weight at har-vest, per acre.	Dry matter.		Protein in dry matter. N. $\times$ 6.25.		Percent. of yield on basis of yield from min'ral plots.	
	Kind.	Weight.						Dry matter.	Pro-tein.
		Lbs.	Lbs.	%	Lbs.	%	Lbs	%	%
0	Nothing, - - - -	—	8,625	19.64	1,694	18.25	309	54	54
7	{ Mixed Minerals, as No. 6a, 480 } { Nitrate of Soda (25 lbs. N.), 160 }	480 } 160 }	15,000	19.31	2,897	21.50	623	92	109
8	{ Mixed Minerals, as No. 6a, 480 } { Nitrate of Soda (50 lbs. N.), 320 }	480 } 320 }	14,650	21.05	3,084	17.13	528	98	92
9	{ Mixed Minerals, as No. 6a, 480 } { Nitrate of Soda (75 lbs. N.), 480 }	480 } 480 }	16,250	19.65	3,133	18.00	564	100	98
6a	{ Dis. Bone-black, { Mixed } { Mur. of Potash, { Min'ls, }	{ 320 } { 160 }	16,625	18.16	3,019	18.44	557	*	*
10	{ Mixed Minerals, as No. 6a, 480 } { Sulph. of Am. (25 lbs. N.), 120 }	480 } 120 }	16,750	17.92	3,002	17.38	522	96	91
11	{ Mixed Minerals, as No. 6a, 480 } { Sulph. of Am. (50 lbs. N.), 240 }	480 } 240 }	19,000	19.02	3,614	18.75	678	115	118
12	{ Mixed Minerals, as No. 6a, 480 } { Sulph. of Am. (75 lbs. N.), 360 }	480 } 360 }	20,250	16.39	3,319	18.56	616	106	108
00	Nothing, - - - -	—	8,375	19.90	1,667	18.31	305	53	53
6b	Mixed Minerals, as No. 6a, 480	480	17,625	18.49	3,259	18.06	589	*	*

\* The average of the yields on plots 6a and 6b is here taken at 100 for comparison.

*The amount of nitrogen in the fertilizer and the proportions of protein in the crop.*—The results in Table 13 show the effect of the nitrogen of the fertilizers upon the yields of dry matter and protein in the cow pea fodder. It will be seen that in general there is very little relation between the percentages of protein in the crop and the amounts of nitrogen used in the fertilizer. For example, the percentage of protein is highest in the crop on the section on which the small ration of nitrogen was applied in nitrate of soda, while the lowest percentage of protein was in the crop on the section on which the medium ration of nitrogen was applied in nitrate of soda. When yields



of dry matter and of protein from the sections supplied with nitrogen are compared with those from the sections supplied with only mineral fertilizers, there appears to be very little increase in either total food materials or protein following the use of nitrogen in the fertilizer. In one of the experiments of the past six years there seemed to be a slight increase in the proportion of protein following an increase in the quantities of nitrogen used, but the increase in that case was not at all regular; and in other years there has been no apparent increase. Altogether, the experiments with cow peas grown for fodder seem to indicate that the nitrogen of the fertilizer has little influence upon the proportions of nitrogen, and thus of protein, in the crop.

#### EXPERIMENTS WITH SOY BEANS.

Soy beans were grown on the two series of sections indicated by the letters B and E in the diagram above. The results on these two series have been combined in the tables beyond as if one series of one-twenty-fifth acre sections had been used. In the experiments with soy beans only the seed is taken into account. No attempt was made to estimate the yields of vines or straw, because as the seeds matured the leaves drop from the plants and become scattered before the time of harvesting the seed.

The amounts and costs of fertilizers per acre, the yields of seed per section as harvested and the estimated yields per acre are given in Table 14. The percentages and amounts of dry matter in the seed and the percentages and amounts of protein in the dry matter are given in Table 15.

*The amounts of nitrogen in the fertilizer and the total yields in the crop.*—The results given in Table 14 indicate the effect of the nitrogen of the fertilizer upon the total yield. The smallest yield was from the sections of the two plots without fertilizer. On the sections of the plots with the mineral fertilizers alone the yields were considerably larger; that from sections of plot 6*b*, however, was a third larger than that from the sections of plot 6*a*. This difference in yield of soy beans from these two plots has been noticeable throughout the series of experiments, suggesting that the soy bean sections of plot 6*a* may be somewhat less fertile than the corresponding



sections of plot 6*b*. On the nitrate of soda group of plots there appeared to be some increase in the yield of seed with the increase in the amount of nitrogen used, the largest yield being found on the sections of the plot with the largest amount of nitrate of soda. On the sulphate of ammonia group of plots, however, the largest yield was obtained in the sections of the plots with the medium amount of sulphate of ammonia. The yields on all the plots with the sulphate of ammonia average a little larger than those on the plots with nitrate of soda. While the yields from the sections of the plots with nitrogen in addition to the mineral fertilizers were considerably larger than from the section of plot 6*a*, the largest yield from the sections with nitrogen in addition to the mineral fertilizers was but little larger than that from plot 6*b* with mineral fertilizer alone.

TABLE 14.

## SPECIAL NITROGEN EXPERIMENTS ON SOY BEAN SEED.

*Weight and cost of fertilizers per acre, total crop, and increase of crop over that of the nothing plots.*

No. of Plot.	FERTILIZERS PER ACRE.			Yield per section (1-25 acre).	Estimated yield per acre.		Gain over nothing plots.
	Kind.	Weight.	Cost.				
		Lbs.	\$	Lbs.	Lbs.	Bu.	Bu.
0	Nothing, - - -	—	—	20.0	500.0	8.3	—
7	{ Mixed Minerals, as No. 6 <i>a</i> , -	480 }	9.64	32.5	812.5	13.5	5.5
	{ Nitrate of Soda (25 lbs. N.), -	160 }					
8	{ Mixed Minerals, as No. 6 <i>a</i> , -	480 }	13.14	36.0	900.0	15.0	7.0
	{ Nitrate of Soda (50 lbs. N.), -	320 }					
9	{ Mixed Minerals, as No. 6 <i>a</i> , -	480 }	16.64	37.5	937.5	15.6	7.6
	{ Nitrate of Soda (75 lbs. N.), -	480 }					
6 <i>a</i>	{ Dis. Bone-black, { Mixed	320 }	6.14	28.0	700.0	11.7	3.7
	{ Mur. of Potash, { Minerals, {	160 }					
10	{ Mixed Minerals, as No. 6 <i>a</i> , -	480 }	10.27	36.0	900.0	15.0	7.0
	{ Sulph. of Am. (25 lbs. N.), -	120 }					
11	{ Mixed Minerals, as No. 6 <i>a</i> , -	480 }	14.39	39.0	975.0	16.2	8.2
	{ Sulph. of Am. (50 lbs. N.), -	240 }					
12	{ Mixed Minerals, as No. 6 <i>a</i> , -	480 }	18.52	36.5	912.5	15.2	7.2
	{ Sulph. of Am. (75 lbs. N.), -	360 }					
00	Nothing, - - -	—	—	18.5	462.5	7.7	—
6 <i>b</i>	Mixed Minerals, as No. 6 <i>a</i> , -	480	6.14	37.5	937.5	15.6	7.6

*The amounts of nitrogen in the fertilizer and the proportion of protein in the crop.*—The effects of the nitrogen of the fertilizer

upon the yields of dry matter and protein in the soy bean seed are indicated by the results in Table 15. As in the experiments with corn (grain), the highest percentage of protein was found in the seed on the sections of the plots without fertilizer. As suggested in the case of the corn, this is probably due to the presence of a large amount of immature or partially developed seed in the crop from those sections. Taken as a whole, the percentage of protein in the seed from the sections which were supplied with nitrogen was considerably larger than in the seed from the sections of the mineral plots, yet there seems to be no constant relationship between the percentages of protein in the seed from the different plots and the quantities of nitrogen used in the fertilizer. As on the average of the experiments for the past four years, the percentages of protein in the seed from the experiments of 1900 have been somewhat the higher from the sections of the plots supplied with the larger quantities of nitrogen, but this result has not been constant.

TABLE 15.

## SPECIAL NITROGEN EXPERIMENTS ON SOY BEAN SEED.

*Percentages and pounds per acre of dry matter and of protein.*

No. of Plot.	FERTILIZERS PER ACRE.		Weight at harvest, per acre.		Dry matter.		Protein in dry matter. N. $\times$ 6.25.		Percent. of yield on basis of yield from min'ral plots.	
	Kind.	Weight.								
		Lbs.	Lbs.	%	Lbs.	%	Lbs.	%	%	
0	Nothing, - - - - -	—	500	89.0	445	46.07	205	60	63	
7	{ Mixed Minerals, as No. 6a,	480 }	813	88.8	722	46.57	336	98	103	
	{ Nitrate of Soda (25 lbs. N.),	160 }								
8	{ Mixed Minerals, as No. 6a,	480 }	900	89.0	801	46.38	372	109	114	
	{ Nitrate of Soda (50 lbs. N.),	320 }								
9	{ Mixed Minerals, as No. 6a,	480 }	938	89.3	838	46.75	392	114	121	
	{ Nitrate of Soda (75 lbs. N.),	480 }								
6a	{ Dis. Bone-black, } Mixed	320 }	700	90.6	634	43.19	274	*	*	
	{ Mur. of Potash, } Min'ls,	160 }								
10	{ Mixed Minerals, as No. 6a,	480 }	900	88.9	800	45.19	362	108	111	
	{ Sulph. of Am. (25 lbs. N.),	120 }								
11	{ Mixed Minerals, as No. 6a,	480 }	975	89.0	868	45.13	392	118	121	
	{ Sulph. of Am. (50 lbs. N.),	240 }								
12	{ Mixed Minerals, as No. 6a,	480 }	913	87.8	802	45.44	364	109	112	
	{ Sulph. of Am. (75 lbs. N.),	360 }								
00	Nothing, - - - - -	—	463	89.7	415	47.69	198	56	61	
6b	Mixed Minerals, as No. 6a,	480	938	89.7	841	44.75	376	*	*	

\* The average of the yields on plots 6a and 6b is here taken as 100 for comparison.

On the whole, the experiments with soy beans seem to indicate that small quantities of nitrogen may be profitably used in growing the crop when the effects on both the total yields of crop and the proportions of protein in the crop are taken into account.

#### SOIL TEST EXPERIMENT.

The purpose of this experiment is to study the deficiencies of soils as regards available plant food, the particular needs of different crops, and the best method of supplying them in fertilizers. The general plan of the experiment consists in dividing the field into similar parallel plots and applying different fertilizers to the different plots, but growing the same crop on all of them.

The soil test of 1900 is the eleventh in a continuous series that has been carried on at Storrs on the same set of plots. The same fertilizers have been applied on the same plots each year, but the crops have been grown in a four-year rotation, as follows: corn, potatoes, oats and either cow peas or soy beans. Each fertilizing material used has been such as would supply only one fertilizer ingredient; nitrate of soda to supply nitrogen, dissolved bone-black to supply phosphoric acid, and muriate of potash to supply potash. These materials have been applied singly, two by two and all three together.

The method of dividing the field into plots for these experiments, and the kinds of fertilizers and the amounts per acre used on each plot, are illustrated by the following diagram. The plots are laid out with the long dimension north and south. The field slopes gently to the south, but with not enough incline to cause serious washing and cutting of the surface by water. The soil of the field is a heavy loam, with a yellow clay loam subsoil. In 1888 and 1889, when the field was being cropped preparatory to being laid out for this series of experiments, it was noticed that the soil seemed to be poorer toward the west side of the field. For this reason the field was divided into two sets of plots, each one twenty-fourth acre in size, and the order of the plots in one of the two sets was reversed, as shown in the diagram. In considering the results of the experiments the data from both plots of the same numbers are combined and the results considered as if obtained from one

plot one-twelfth acre in size. In this way errors due to the irregularities of the soil are partially eliminated.

*Diagram illustrating the arrangement of the plots in the soil test, and the kinds of fertilizers and amounts per acre used on each plot.*

Unfertilized strips separate the adjoining plots.

EAST.

NORTH.	PLOT O. Nothing.	SOUTH.	PLOT Y. Stable manure, 16000 lbs.
	PLOT A. Nitrate of Soda, 160 lbs.		PLOT X. { Stable manure, 10000 lbs. Dis. Bone-black, 160 lbs.
	PLOT B. Dis. Bone-black, 320 lbs.		PLOT OOO. Nothing.
	PLOT C. Mur. of Potash, 160 lbs.		PLOT G. { Dis. Bone-black, 320 lbs. Mur. of Potash, 160 lbs. Nitrate of Soda, 160 lbs.
	PLOT OO. Nothing.		PLOT F. { Dis. Bone-black, 320 lbs. Mur. of Potash, 160 lbs.
	PLOT D. { Dis. Bone-black, 320 lbs. Nitrate of Soda, 160 lbs.		PLOT E. { Mur. of Potash, 160 lbs. Nitrate of Soda, 160 lbs.
	PLOT E. { Mur. of Potash, 160 lbs. Nitrate of Soda, 160 lbs.		PLOT D. { Dis. Bone-black, 320 lbs. Nitrate of Soda, 160 lbs.
	PLOT F. { Dis. Bone-black, 320 lbs. Mur. of Potash, 160 lbs.		PLOT OO. Nothing.
	PLOT G. { Dis. Bone-black, 320 lbs. Mur. of Potash, 160 lbs. Nitrate of Soda, 160 lbs.		PLOT C. Mur. of Potash, 160 lbs.
	PLOT OOO. Nothing.		PLOT B. Dis. Bone-black, 320 lbs.
	PLOT X. { Stable manure, 10000 lbs. Dis. Bone-black, 160 lbs.		PLOT A. Nitrate of Soda, 160 lbs.
	PLOT Y. Stable manure, 16000 lbs.		PLOT O. Nothing.

WEST.

In addition to the plots in the regular soil test, which include the plots from o to ooo inclusive in the above diagram, and are treated with the commercial fertilizers as explained, two other plots, X and Y, of the same size, are included in the series,



the former being treated with stable manure and phosphoric acid, and the latter with a larger quantity of stable manure, but without the addition of the mineral fertilizer.

TABLE 16.  
SOIL TEST WITH FERTILIZERS ON OATS.

BY THE STATION, STORRS, 1900.

No. of Plot.	FERTILIZERS PER ACRE.			YIELD PER PLOT. (1-12 Acre.)		ESTIMATED YIELD PER ACRE.		
	Kind.	Weight.	Cost.	Oats.	Straw.	Oats.*	Straw.	Gain over nothing plots.
		Lbs.	\$	Lbs.	Lbs.	Bu.	Lbs.	Bu.
O	Nothing, - - -	—	—	60.5	98.0	22.7	1176	—
A	Nitrate of Soda, - -	160	3.50	76.5	106.0	28.7	1272	6.3
B	Dis. Bone-black, -	320	2.65	95.0	119.0	35.6	1428	13.2
C	Muriate of Potash, -	160	3.49	70.0	91.5	26.3	1098	3.9
OO	Nothing, - - -	—	—	59.5	73.5	22.3	882	—
D	{ Nitrate of Soda, - -	160 }	6.15	100.5	150.5	37.7	1806	15.3
	{ Dis. Bone-black, - -	320 }						
E	{ Nitrate of Soda, - -	160 }	6.99	94.5	135.5	35.4	1626	13.0
	{ Muriate of Potash, - -	160 }						
F	{ Dis. Bone-black, - -	320 }	6.14	74.0	120.5	27.8	1446	5.4
	{ Muriate of Potash, - -	160 }						
G	{ Nitrate of Soda, - -	160 }	9.64	97.5	189.0	36.6	2268	14.2
	{ Dis. Bone-black, - -	320 }						
OOO	Nothing, - - -	—	—	59.5	107.5	22.3	1290	—
X	{ Stable manure, - -	10,000 }	7.99	107.5	172.5	40.3	2070	17.9
	{ Dis. Bone-black, - -	160 }						
Y	Stable manure, - -	16,000	10.68	130.2	245.5	48.8	2946	26.4

\* 32 lbs. per bushel.

*Experiment of 1900.*—Oats were grown in the soil test of the past year. This is the third time this crop has been grown on these plots since the series of experiments was begun. The results of the experiment of 1900 are given in Table 16. The differences in the appearance of the crop on the different plots were quite marked throughout the season. The effect of the lack of nitrogen in the soil of those plots upon which no nitrogenous fertilizer was applied was quite noticeable in the pale color of the leaves and stems. On the plots with commercial fertilizers the ingredient which appears to have had the most marked effect on the yield was phosphoric acid (plot B.) The yield of seed on this plot was at the rate of seven bushels per



acre higher than on the nitrate of soda plot (A). In the experiment of 1900 phosphoric acid seems to have taken the lead in affecting the yields both of grain and of straw, while nitrogen stood second in its effects. This was not the case in the oat experiments of this series in 1892 nor in 1896. Each of those years the best yield of grain on the plots with commercial fertilizers seemed to result from the use of nitrogen from nitrate of soda, although the plots supplied with phosphoric acid from dissolved bone-black gave the second best results. As in previous years, the largest yields in the oat experiment for 1900 were obtained on the plots supplied with manure. This was probably due to the fact that in the soil of the manured plots there would be humus present, one advantage of which would be a tendency to check the evaporation of water, while the plots supplied with commercial fertilizers would probably be deficient in humus, a condition that would favor evaporation.

By continuing the experiments through a number of years, and thus repeating each crop several times, the inequalities and errors in results due to irregularities of the seasons are to some extent eliminated in the final averages. Corn, potatoes, and oats have each been grown three times thus far during the course of the experiment. The average of the yields for the three different years for each of these crops is given in the following table summarizing the results of the past eleven years. The yields of oats in the experiment of 1900 are also given in the table in comparison with the average. From the results here summarized it will be observed that the yield of oats has been largest on the plot with stable manure. On the plots with the chemical fertilizer the average yield was largest on plot D, with nitrogen and phosphoric acid together, while that on plot C, with potash alone, was little larger than that on the plots without fertilizer. The indication is that on this particular soil the oat crop needs to be liberally supplied with nitrogen and phosphoric acid. Considering the results of all the experiments with all the crops, there seems to be no striking deficiency of any one of the ingredients—nitrogen, phosphoric acid or potash—in this particular soil. The special requirements for fertilizers seem to be determined more largely by the needs of the particular crop than by peculiarities of the soil.

TABLE 17.

*Average yields per acre in Station soil test during eleven years.*

No. of Plot.	FERTILIZER.		Oats (seed).		Corn, avg. for 3 years, 1890, 1894, 1898.	Potatoes, avg. for 3 years, 1891, 1895, 1899.	Cow peas (vines), 1893.	Soy beans (seeds) 1897.
	Kind.	Weight per acre.	Experiment of 1900.	Avg. for 3 years, 1892, 1896, 1900.				
		Lbs.	Bu.	Bu.	Bu.	Bu.	Lbs.	Bu.
O	Nothing, - -	—	22.7	27.1	28.7	66.0	10230	6.8
A	Nitrate of Soda, -	160	28.7	34.6	33.6	61.4	10960	6.2
B	Dis. Bone-black, -	320	35.6	32.5	32.8	64.3	10710	7.1
C	Muriate of Potash, -	160	26.3	26.8	30.9	108.1	11680	6.4
OO	Nothing, - -	—	22.3	24.3	23.8	50.3	9725	7.1
D	{ Nitrate of Soda, -	160 }	37.7	40.9	36.8	67.5	12920	9.0
	{ Dis. Bone-black, -	320 }						
E	{ Nitrate of Soda, -	160 }	35.4	35.6	36.7	119.8	13335	7.6
	{ Muriate of Potash, -	160 }						
F	{ Dis. Bone-black, -	320 }	27.8	30.7	35.5	139.8	15790	9.3
	{ Muriate of Potash, -	160 }						
G	{ Nitrate of Soda, -	160 }	36.6	42.2	43.7	170.1	16210	8.6
	{ Dis. Bone-black, -	320 }						
OOO	{ Muriate of Potash, -	160 }	22.3	24.7	28.5	55.1	12100	7.7
	{ Nothing, - -	— }						
X	{ Stable manure, -	10,000 }	40.3	43.3	47.1	136.1	15795	11.5
	{ Dis. Bone-black, -	160 }						
Y	Stable manure, -	16,000	48.8	48.4	47.8	165.6	15875	12.7

## SUMMARY AND GENERAL DEDUCTIONS.

*The special nitrogen experiments here reported were made with corn, cow peas, and soy beans. The purpose of the experiments is twofold: First, to study the effects upon the yields of the crops when different kinds and quantities of nitrogenous fertilizers are used in addition to uniform quantities of mineral fertilizers; and second, to study the effect of the nitrogen in the fertilizers upon the percentage and amount of protein in the crops.*

*The experiments with corn indicate that while the mineral fertilizers were very essential to the corn crop, they were not sufficient for this crop or this soil when used alone. A complete fertilizer with nitrogen, phosphoric acid and potash was essential for good yields of corn. When the yields alone are considered, the most profitable results financially have been obtained with 25 to 50 pounds of nitrogen per acre (in nitrate of soda) used in connection with mineral fertilizers. When the feeding value of the crop is considered even larger quantities of nitrogen than 50 pounds per*

acre seem to give profitable returns. While the yield of dry matter has not generally been much increased by an increase of nitrogen beyond 50 pounds per acre, the percentages of nitrogen and of protein in both the grain and the stover have usually been highest in the crops where the largest quantities of nitrogen have been used in the fertilizer.

The experiments with legumes, cow peas, and soy beans, indicate that mineral fertilizers are of great value in increasing the yields of these crops, while nitrogenous fertilizers do not greatly increase either the yield or the percentage of protein in the crop over that obtained from the mineral fertilizers only. In the experiments thus far made by the Station the average results with cow pea fodder show practically no advantage from the use of nitrogenous fertilizers. In the experiments with soy beans grown for seed some increase seems to have resulted from the use of nitrogenous fertilizers, although that increase was small. The percentages and yields of protein in these legumes bore very little relation to the quantities of nitrogen used. The soy bean seeds, on the average, showed a slightly higher percentage of protein on plots supplied with nitrogen than on the plots supplied only with mineral fertilizers. But, on the whole, the experiments with cow pea fodder and soy beans seem to show that there is little to be gained by the use of nitrogen in the fertilizers, while an abundance of the mineral ingredients is very essential to securing good crops on soils and under circumstances similar to those of the experiments here described.

The results of the soil test experiment indicate that nitrogen and phosphoric acid are of prime importance for use on this particular soil in order to get good yield of oats. The same ingredients also produced the most marked results on the yields of corn during the three years in which this crop has been grown in the rotation. On the other hand, potatoes have responded more generally to the use of potash. In general, then, the results seem to show that on this particular soil the peculiarities of the crop are of more importance than the deficiencies of the soil in regulating the demands of the fertilizers. It is not wise, however, to base too broad generalizations on the results here obtained, for, in many cases where soil tests have been made by the Station on different farms throughout the State, the soil has been the controlling factor in regulating the demands for fertilizers.

## AN EXPERIMENT ON SOIL IMPROVEMENT.

BY C. S. PHELPS.



An experiment on soil improvement was begun by the Station on a series of plots of land at Storrs in the spring of 1899, to be continued through a period of years. The soil on which the experiment is being carried out appears to be lacking in organic matter and probably in available nitrogen. Such a soil is commonly spoken of as "poor" or "worn out." The purpose of the experiment is to compare the value and economy of different methods of manuring for restoring fertility to a soil of this kind. The fertilizers used in the experiments, the kinds and quantities of which are fully explained in a later paragraph, are (1) stable manure, (2) a "complete" chemical fertilizer, and (3) "green" manures, both alone and in combination with mineral fertilizers. The plan of the experiments is given in detail beyond.

The field selected for this experiment is one which had been used for a peach orchard since 1889. While the peach trees were growing the field had been liberally treated with mineral fertilizers, but not very much nitrogen had been supplied. During the years 1889 to 1894 different crops had been grown between the rows of trees and had been removed from the land; after 1894 the land remained under cultivation most of the time, but without cropping. Part of the peach trees were removed in the fall of 1897 and the balance in the fall of 1898. When the field was plowed in the spring of 1899 the soil, which is a medium heavy loam and holds moisture well, was compact and hard and seemed to be lacking in organic matter.

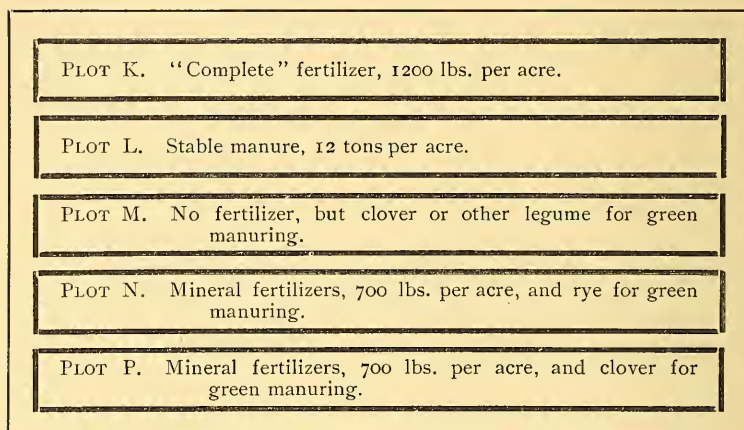
*Plan of the experiment.*—The general plan of the experiment is to grow a rotation of crops, having the same crop on all the plots each year, to use manure or fertilizers on the different plots in such a way as to "build up" the general fertility of



the soil and to study the economy of the different methods employed for this purpose. The arrangement of the plots and the method of fertilizing each is shown in the following diagram.

*Diagram illustrating arrangement and method of fertilizing plots in experiment on soil improvement.*

The narrow strips at the sides and ends of the plots are without fertilizer.



The plots contained one-eighth acre each, and are separated by narrow strips 3.3 feet wide. These strips between the plots are planted, as well as a similar strip on the outside of the field, the same as the plots, but no fertilizers are used on them. The crop from these strips is harvested before that on the plots, and the yields obtained on them are not included in the experiment. The following rotation has been planned: corn, potatoes, oats and peas for fodder, and soy beans. On plots K and L it has been planned to use approximately the same value of plant food, estimating the fertilizer by the usual system of valuation adopted by the New England Experiment Stations and estimating the manure at \$3 per cord. Plot K is supplied with a liberal quantity (1200 pounds per acre) of a complete fertilizer, the ingredients used and rates per acre of each to be as follows: nitrate of soda, 200 pounds; sulphate of ammonia, 100 pounds; tankage, 200 pounds; muriate of potash, 200 pounds; and South Carolina acid phosphate, 500 pounds. Plot L is supplied with



a mixed stable manure at the rate of 12 tons or  $5\frac{1}{2}$  cords per acre. It will be seen that the valuation of the materials used on these two plots is nearly the same per acre, if the manure is reckoned at \$3 per cord.

Plot M has had no fertilizer for the past two years, but whenever practicable some leguminous crop has been grown between the seasons of the regular crops from year to year for the purpose of plowing under. Clover was grown for this purpose after the corn crop of 1899 and was plowed under in the spring of 1900.

Plots N and P are designed to be similarly fertilized by the use of a mixture of South Carolina acid phosphate and muriate of potash. This mixture is used on each of these plots in the following proportions per acre: acid phosphate, 500 pounds; muriate of potash, 200 pounds. On plot N it is planned to grow, for plowing under between the times of the regular crops, some cereal crop, like rye. This crop followed the corn crop of 1899 and was plowed under before the crop of 1900 was planted. On plot P the same fertilizers have been used as on N, but a legume has been grown to plow under in place of the rye on plot N. Clover was grown for the purpose after the corn crop of 1899.

Whenever possible, it is the plan to grow a crop for plowing under on plots M, N, and P, between the crops of the regular rotation. The experiment for 1899 with corn was necessarily a preliminary test, as it was not practicable to grow a catch crop for plowing under previous to starting the experiment in the spring of 1899. Alsike clover was, however, sown amongst the growing corn on plots M and P late in July, 1899. The clover made a fair growth the fall of that year and early in the season of 1900. It was about three inches high and covered the ground in a thick mat when plowed under, April 12, preparatory to planting the potatoes. Plot N was sown to rye October 10, 1899, and this was plowed under at the same time that the clover was on plots M and P. The rye was about three feet high and in bloom when plowed under.

*The yield of potatoes for 1900.* The crop made a vigorous growth on all of the plots. The potato vines were sprayed twice for the blight, with Bordeaux mixture. The plants

remained green until early in September, and all of the conditions seemed to indicate a normal growth. The following table shows the yields of "merchantable" and of small potatoes on the different plots.

TABLE 18.

*Yields of potatoes in the experiment on soil improvement.*

No. of Plot.	FERTILIZERS.			YIELD PER PLOT. ( $\frac{1}{2}$ acre.)		ESTIMATED YIELD PER ACRE.	
	Kind.	Weight per acre.	Cost per acre.				
				Good.	Poor.	Good.	Poor.
		Lbs.	\$	Lbs.	Lbs.	Bu.	Bu.
K	Complete fertilizer, - -	1,200	17.29	1,426	109	190.1	14.5
L	Stable manure, - - -	24,000	16.00	1,339	110	178.5	14.6
M	No fertilizer except clover,	—	—	1,376	94	183.1	12.5
N	Mineral fertilizer and rye, -	700	7.59	1,136	172	151.4	22.9
P	Mineral fertilizer and clover,	700	7.59	1,334	147	177.8	19.6

As previously explained, the cost of fertilizer was intended to be about the same for both plots K and L. The only cost for fertilizer on plot M was that of the clover seed and the time used in sowing it. This is not taken into account. On plots N and P there was the cost of the mineral fertilizer in addition to the expense of growing the catch crops. For these two plots the cost was less than half that for plots K and L.

Considering the good or merchantable potatoes only, the largest yield was obtained on plot K with the complete fertilizer, and the smallest on plot N with the mineral fertilizer and rye. The second best yield was obtained on plot M with no fertilizer but clover. The yields on plot L with stable manure and plot P with mineral fertilizer and clover were practically the same, and were a little smaller than that on plot M with clover alone. From a comparison of the yields on plots P and M there seems to have been no benefit from the use of the mineral fertilizer. However, plot M was on slightly lower ground than plot P, and probably received more moisture, which would tend to increase the yield. Even allowing for this, the yield from plot M as compared with those from the other plots indicates that clover had a high value as manure in this experiment. Its superiority to rye in this respect is seen in comparing the yield from plot N with that from plot P.

*General deductions.*—From the results of this experiment it will be seen that clover had a high value when used to plow under as manure for potatoes. By sowing the clover seed amongst the corn in July, this crop was grown mainly between the seasons of the regular crop of the rotation. Although the clover at the time of plowing under was only three or four inches high, it proved to be a very valuable manure. The advantages in growing clover in this way for use as green manure are mainly four: (1) The expense is very little as the catch crop of clover does not interfere with the regular system of rotation and no additional plowing or harrowing is necessary. (2) The clover tends to prevent the loss of nitrogen through leaching or washing during that portion of the year when the soil is usually bare. (3) The clover growing on the soil will prevent washing and cutting of the surface of the soil. (4) The clover takes up considerable nitrogen from the air which, when the crop is plowed under, becomes available to the succeeding crops.

## INVESTIGATIONS ON THE SOURCES OF THE ACID ORGANISMS CONCERNED IN THE SOURING OF MILK.

BY ROLLIN H. BURR.

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Investigations of the acid organisms of milk date back to 1877, when Lister discovered in milk an organism which he called *Bacterium lactis*. Subsequently Hueppe isolated and made a more careful study of what was probably the same organism, and named it *Bacillus acidi lactici*. After him Marpmann, Grotenfelt, Keyser, and many others, isolated from souring milk bacteria agreeing with this bacillus, while other investigators have found in sour milk many different organisms capable of producing lactic acid, but not resembling the organism of Hueppe. It was, therefore, for a time believed that there is no distinct lactic bacterium concerned in the souring of milk, but that there is quite a large number of such bacteria any one of which may be concerned in the milk souring. The work of more recent years has, however, shown that this is hardly correct. In 1894 Gunther and Thierfelder published the result of work, from which they concluded that the organism of Lister and Hueppe was the common cause of the normal souring of milk in Europe. Since then other confirmatory experiments have been published. Esten, in 1896, published the results of investigations made upon milk from various parts of the United States, from which he concluded that the ordinary souring of milk in this country is due chiefly to one organism.\* This bacterium is probably identical with that found by Gunther and Thierfelder, and was given the same name by Esten, *B. acidi lactici*. It has been more recently found that associated with this species in this vicinity are two other lactic bacteria found almost universally and contributing to the souring of milk, although commonly present in far less numbers. These two are *B. lactis aerogenes* and a species

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\* Storrs Station Report, 1896, p. 44.

which Conn has called *B. acidi lactici* II.\* These three organisms are apparently the only common organisms concerned in the souring of milk in this region.

THE IMPORTANCE OF A KNOWLEDGE OF THE SOURCES OF  
THESE ORGANISMS.

For a number of reasons it is particularly important to know the source of the acid organisms in milk. In the first place, the industry of furnishing sweet milk to cities finds in the lactic bacteria its greatest obstacle. In warm weather particularly, in spite of all that can be done, milk is almost sure to sour. If it could be definitely shown where these lactic organisms come from, it might be possible to devise simple means of guarding against them and thus aiding in the process of preserving milk.

In the ripening of cream for butter making the problem of milk bacteria is of no less importance. It has been quite definitely shown that the flavors of the butter are due to the character of the ripening, and that the character of the ripening depends, in considerable degree at least, upon the kind of bacteria which chance to be present in the cream. The varieties of bacteria present in normal cream during ripening are numerous, but, as is shown in an article by Conn and Esten in this Report,† the lactic bacteria play a very important part in this process.

In the use of artificial cultures for cream ripening, adopted quite widely in some countries, it has been found necessary to pasteurize the cream in order to get rid of the noxious bacteria that chance to be present and then subsequently to inoculate with an artificial culture. In the article just referred to it has been shown that in ripened cream *B. acidi lactici* (Esten) comprises commonly 90 per cent. or more of the organisms present, the numbers being small in the fresh milk and cream, but under normal conditions increasing rapidly until the milk or cream sours and curdles. Evidently if the source of these as well as the other lactic organisms could be accurately determined it might be possible to keep them out of milk, and if this could be done the problem of the use of artificial cultures would be very greatly changed.

\* Storrs Station Report, 1899, pp. 13-67.

† See pp. 13-33.



It is evident then that both for the industry of furnishing sweet milk to cities and for the butter-making industry, an accurate knowledge of the source of the lactic bacteria is desirable. To determine if possible the actual source of these organisms was the object of the experiments here reported.

#### EXPERIMENTS ON THE SOURCE OF THE LACTIC ORGANISMS.

In the investigations reported in the following pages the effort was made to discover particularly the source of *B. acidi lactici*, inasmuch as this has proved to be the most widely distributed of the lactic bacteria and the one which forms ordinarily over 90 per cent. of the bacteria in ripened cream. Secondarily, attention was also turned to the source of the two other lactic organisms. Previous to the work of Esten no definite suggestions were made as to the source of these organisms. Esten made a few experiments to determine whether the organism which he isolated came from hay or dust or from the teats of the cow. In his experiments neither hay nor the dust of the cow stall gave him any evidence of the presence of the *B. acidi lactici*. This fact, together with some other experiments, suggested to him the possibility that the natural home of the organism in question was the milk duct; but these organisms have not been found hitherto in the udders of cows when these have been examined bacteriologically. It is possible, however, that they have escaped the attention of those who have examined the udders, because of difficulty of detecting them with ordinary culture media. Moreover, as indicated above, *B. acidi lactici* has not been found very abundant in fresh milk or cream, although apparently universally present in large numbers in ripened cream. It may be, however, that the bacterium was present in small numbers even in freshly drawn milk, but escaped observation on account of difficulty of investigation. To determine whether or not this organism is actually present was one particular purpose of the following experiments.

#### GENERAL DESCRIPTION OF EXPERIMENTS.

Three different series of experiments have been made, the first two consisting of the studies of milk as drawn directly from the cow, and the third consisting of a bacteriological

examination of the udders of cows. The first series, comprising Experiments 1-10, was carried out during 1900. The second, comprising Experiments 11-15, was conducted a year later. The third series was also carried out in 1901. The investigations were made by the writer while an assistant in the bacteriological laboratory of the Connecticut Hospital for the Insane.

*Subjects and conditions.*—The herd which was used in the experiments consisted of perfectly healthy cows, typical in every respect of the best kept cows of the farmer. It consisted of nearly a hundred cows, mostly of the Holstein breed. The herd was owned by the Connecticut Hospital for the Insane, and the success of the experiments was in large degree due to the excellent condition of this herd and its surroundings. The barn was perfectly ventilated and slightly warmed by steam. The heat from the steam produced a slight upward current of air which passed through a large number of windows opening in the roof directly above the stalls, and thus established a complete ventilation. The floors were of hard cement and were cleaned four or five times each day. The cows were groomed morning and night, and during the warm summer months were sprayed with a disinfectant. All utensils of the dairy were thoroughly scalded and kept well polished. The cows when not feeding in the pasture were given ensilage. In short, the conditions were those of a model dairy.

*Preparation of media.*—In the experiments a variety of culture media were tested, some of them being those commonly used in bacteriological laboratories, while others were especially devised for the purpose. Some experiments were made with media made from milk, but it was found that the litmus-milk-sugar gelatin, which has been used by Esten and Conn in their experiments, was most satisfactory, and eventually all other media were discarded and the experiments detailed below were all performed with this medium.

#### FIRST SERIES OF EXPERIMENTS.

*Experiment No. 1.*—The object of the first experiment was to determine whether milk as freshly drawn from the cow contains acid organisms or whether the acid organisms are a

contamination entering the milk during or after the milking. This experiment was performed with a single cow, No. 81. The milk of this cow was drawn into a two-quart sterile pail,  $2\frac{1}{2}$  minutes being required for milking. At the same time samples of milk were drawn into sterile glass tubes holding 10 cc., in such a way as to prevent as much as possible any contamination from external sources. These tubes had a very small opening and were quickly plugged with cotton after the milk was drawn. The milk from these sample tubes was plated in gelatin and carefully examined for the presence of acid organisms, but none were found. The milk drawn in the pail was allowed to stand until the cream separated, and then examination was made of the cream. This showed an average of 161,000,000 organisms per cc. Of these about 50 per cent. were *B. acidi lactici*, 20 per cent. *B. acidi lactici II.*, 5 per cent. *B. lactis aerogenes*, and the remainder consisted of miscellaneous bacteria. This same cream was tested after a more complete ripening (39 hours) and found to contain 268,000,000 bacteria per cc., of which 85 per cent. were *B. acidi lactici*, the other lactic organisms having decreased proportionately. This experiment evidently indicates that the milk became contaminated with acid organisms either during or after milking, but apparently did not contain them when freshly drawn.

*Experiment No. 2.*—This experiment was confirmatory of the first, but was conducted on a slightly different plan. A different cow was chosen, No. 50. Milk was drawn into sterile tubes as before, and also into a tall sterilized jar which had a comparatively narrow mouth, the chief difference between this experiment and the last being in the size of the opening of this jar as compared with the pail used in the previous experiment. Bacteriological examination of the samples in tubes were made at once and showed an average of 500 organisms per cc., but none of the three species of lactic organisms were present. The milk in these tubes did not curdle in 28 days, but remained sweet and palatable for this length of time. The milk in the jar, which was closed by a cotton plug, was allowed to stand until the cream had arisen, and then a bacteriological examination was made of the cream. This cream showed at first 600,000 organisms per cc. When partially ripened 68,000,000

were found, and when fully ripened about 150,000,000 organisms per cc. Among these bacteria were found large numbers of *B. acidi lactici* II. and *B. lactis aerogenes*, with a quantity of miscellaneous bacteria, but no single colony of *B. acidi lactici* was detected.

*Experiment No. 3.*—This experiment was conducted precisely as the last and designed as a confirmatory test. The results were identically the same so far as concerns the variety of bacteria. From these two experiments it was evident that when sufficient care was taken in drawing the milk in sterile vessels milk could be obtained which was free from the presence of *B. acidi lactici*, although it was more difficult to exclude the other two species of lactic bacteria.

*Experiments Nos. 4, 5, and 6.*—In these experiments the attempt was made to determine whether the acid organisms were present in the dirt and dust which fell from the cows into the milk pail during the milking. Milk was drawn into sterile tubes and also into a sterile jar as in the preceding experiments, but in addition gelatin plates were exposed for different lengths of time under the body of the animal so as to catch some of the dust and dirt which fall during the milking. The results obtained with the sterile tubes and the jar of milk were practically identical with those of the preceding experiments. A study of the gelatin plates gave the following results:

*Gelatin plates 10 cm. diameter exposed under the cow in the stall.*

TIME OF EXPOSURE.							NUMBER OF COLONIES ON PLATE.	
							In Experiment No. 4.	In Experiment No. 6.
10 seconds,	-	-	-	-	-	-	380	52
20 seconds,	-	-	-	-	-	-	382	100
30 seconds,	-	-	-	-	-	-	1,736	195
40 seconds,	-	-	-	-	-	-	3,294	500

A study of the species of bacteria found on these plates showed the presence of *B. acidi lactici* II. and *B. lactis aerogenes*, together with large numbers of miscellaneous bacteria. However, no *B. acidi lactici* were found. It was thus shown that two of the common lactic bacteria were found in the dust and



dirt from the cow and the stable and made their way into the milk during the milking. Inasmuch as it had also been previously found that hay or hair from the cows' limbs showed the presence of these two organisms, the conclusion was inevitable that one source of *B. acidi lactici* II. and *B. lactis aerogenes* was the dirt and dust of the stable. They were, therefore, a secondary contamination of the milk. It was, however, surprising that *B. acidi lactici* I. was *not* found on these plates in spite of the fact that it is so universally present in the later stages of milk souring. It was thought that the explanation of this might probably be that they were present in small numbers, but owing to the numerous liquefying colonies found in the gelatin plates, could not be detected before the gelatin plates were completely liquefied.

Parallel with these experiments a study was made of the ripening of cream obtained from the milk. Inasmuch, however, as Conn and Esten in a previous paper in this Report have thoroughly discussed the subject of cream ripening, the results of these experiments will be omitted. It need only be stated that the results were identical with those obtained by Conn and Esten, namely, that unripened cream contains small numbers of lactic bacteria, but that these increase rapidly during the ripening until at its close they comprise over 90 per cent. of the whole.

*Experiments Nos. 7, 8, and 9.*—In the previous experiments the work was confined in each case to a single cow. The question then arose whether it might not be possible that the milk of these particular cows contained no lactic organisms, but that this would not be true of the milk of cows in general. To settle this question the following experiment was performed: In the barn there were 70 cows that could be used for these experiments, and upon three successive days milk was drawn from each one of the 70 cows immediately into sterile vials such as before used, each vial being marked with the number of the cow from which the milk was drawn. The vials were plugged with sterile cotton, the cotton being removed only for the milking and immediately replaced, so that the milk had only a few second's exposure to the air. It was believed that in this way most of the external contamination of the milk



might be avoided. In all there were 205 such tubes obtained from the 70 cows. The first set of tubes were kept at about  $18^{\circ}$  C.; the second and third sets were kept in an incubator at  $35\frac{1}{2}^{\circ}$  C. for 72 hours. Of the first set of 70 tubes only 5 had curdled in the course of 6 days. Plate cultures made from these 5 tubes showed the presence of *B. acidi lactici* in 2 of them, while in the other 3 there were *B. lactis aerogenes* and several miscellaneous bacteria. Of the second set a large number curdled, 31 in all. These were all examined by means of plate cultures. Of the 31 tubes, 6 showed the presence of *B. acidi lactici*, and all contained the two other lactic bacteria. In the third set, 12 tubes curdled, all of which were examined by plate cultures, but in none of them was *B. acidi lactici* discovered. In comparing the three sets together it was found that in no case did the milk from the same cow curdle in all three tests. In 12 cases only did the milk from the same cow curdle in two of the tests, and in all of these cases careful plate cultures failed to reveal the presence of *B. acidi lactici*.

In these tests 8, as indicated, showed the presence of *B. acidi lactici* in the milk. To determine whether this organism was actually present in the fresh milk of the cows furnishing these samples, the 8 cows were again tested in the same way as before, this time 5 samples being taken from each cow. In the milking in this case the plugging of the tubes with cotton was slightly delayed, so that the chances for air contamination were a little greater than in the previous test. Of these 40 tubes, all of which were placed at  $35\frac{1}{2}^{\circ}$  C. for 48 hours, a single one alone showed the presence of *B. acidi lactici*. The cow furnishing this milk was again tested by having samples taken in sterile tubes during the milking. In this case the milking was more rapid and the possibility of secondary contamination lessened. These tubes were placed at  $35\frac{1}{2}^{\circ}$  C. for 36 hours, but in no case was *B. acidi lactici* present.

These experiments plainly indicated that the freshly drawn milk from this herd does not contain *B. acidi lactici*. As a confirmatory test, in order to demonstrate that the milk from this barn is not different from the milk of ordinary dairies in respect to the presence of this organism, the following simple experiment was made: Milk was taken from the milk cans containing the mixed milk of the whole herd. The samples of

milk were placed in sterile tubes, plugged with cotton immediately, and set aside at 20° C. At the end of two days a typical curdling had taken place in every tube, and an examination of the milk showed the universal presence of *B. acidi lactici*. The only conclusion that could be drawn from these experiments was, then, that the *B. acidi lactici* does not come from the milk duct, but is a secondary contamination of the milk from the outside, and, therefore, that if sufficient care is taken, milk can be drawn without being contaminated with lactic bacteria.

Up to this point, then, experiments have warranted the following conclusions:

1. Milk when first drawn may contain many liquefying and miscellaneous bacteria with but few or no acid organisms.

2. The acid organisms are probably an outside contamination.

3. These acid organisms, though few at first, rapidly multiply in the milk, soon checking the growth of the liquefiers and miscellaneous bacteria.

4. Unripened cream or sweet milk contains from 50,000 to 2,000,000 bacteria per cubic centimeter, but this number increases rapidly for 24 hours and finally reaches several hundred millions.

5. Ripened cream has bacteria varying from 55 million to a billion and a half or more in each cubic centimeter, and of this large number commonly over 90 per cent. are *B. acidi lactici*, although this species is absent in freshly drawn milk and present only in very small numbers in sweet milk.

#### SECOND SERIES OF EXPERIMENTS.

At this point the experiments were interrupted; but a year later, in the spring of 1901, they were resumed for the purpose of more strictly demonstrating the previous conclusions and also determining by *positive* evidence, if possible, the source of the widespread *B. acidi lactici*.

*Experiment No. 11.*—This experiment was merely a repetition of three of those in the first series. It consisted in drawing milk from a large number of cows into sterile vials, only such cows being chosen as could be milked with the

greatest freedom. This was done in order to reduce as low as possible the chance of contamination. The tubes were exposed to the air only a very few seconds during the milking, and were immediately plugged with cotton. Forty-five tubes were thus filled and set aside at about 20° C. At the end of 72 hours 5 tubes had curdled, but were not strongly acid. Plate cultures made from them showed that not one of the tubes contained *B. acidi lactici*; of the remaining 40 tubes some failed to curdle, some curdled with a slightly alkaline reaction, some remained neutral, while others became slightly acid, but failed to curdle until heated.

*Experiment No. 12.*—The next experiment was designed to show, if possible, the actual source of the organism studied. If the *B. acidi lactici* is present in the dust and dirt of the stable it ought to be found by direct examination. The experiment previously performed of exposing gelatin plates under the flank of the cow is unsatisfactory, because the great number of liquefying bacteria prevents a thorough examination of the plates. To determine whether *B. acidi lactici* is present in the dirt a large number of test tubes of *sterile milk* were set in various places in the barn, and left exposed to the air for 12 hours. Each of these tubes contained about 6 cc. of milk which had been carefully sterilized by steam on 3 successive days. The opening of each tube measured about 10 millimeters. After remaining exposed in the air for 12 hours they were plugged and brought to the laboratory and left at a temperature of about 20° C. In 48 hours every tube had curdled, was strongly acid, and had the type of curdling characteristic of *B. acidi lactici*. As soon as the milk became acid plate cultures were made. The *B. acidi lactici* II. and *B. lactis aerogenes* were easily recognized in these plates, but in this experiment no *B. acidi lactici* were found. It was, however, thought possible that this organism was overlooked because of the presence of rapidly liquefying organisms. The characteristic growth of *B. acidi lactici* only appears after 3 days' cultivation, and when liquefiers are numerous it is impossible to detect the presence of this organism. As the liquefiers in the first experiment were quite abundant, a second experiment of a similar character, but with slight modification, was undertaken.

*Experiment No. 13.*—This experiment was conducted precisely similar to the previous one, with the exception that some of the tubes were placed in a more concealed place, where they were less likely to be directly contaminated with dirt. Three tubes of sterile milk were placed in a position where they were well exposed to the air, and five were hidden behind a tall board near a window several feet from the cows, where little dust would be likely to reach them. After the tubes had been exposed 12 hours they were plugged with cotton and placed in the laboratory. Those which had been most exposed to the dust became strongly acid and in 36 hours had curdled. These tubes were tested by the ordinary plate cultures and were found to contain all of the three acid varieties, including the *B. acidi lactici* which was sought. The tubes which had been hidden behind a board, however, did not curdle before 72 hours, and plate cultures failed to show the presence of *B. acidi lactici*. They were, however, slightly acid and contained the two other species of lactic bacteria.

*Experiment No. 14.*—Sterile milk tubes were exposed in the open stable for 12 hours and then plugged and brought to the laboratory, as in the previous experiments. All tubes curdled and became acid. They were tested with plate cultures in the ordinary way and large numbers of each of the three species of lactic bacteria were found in them.

*Experiment No. 15.*—A final test was made as follows: Tubes of sterile milk were exposed for about 20 minutes underneath several of the cows during the process of milking. At the same time samples of milk from each cow were drawn directly into sterile vials and plugged at once. In this way *sterile* milk was exposed to external contamination, while the *fresh* milk was drawn in such a way as to prevent external contamination. The samples of milk which were drawn directly into sterile vials failed to curdle and contained no acid organisms, as in all the previous experiments. On the other hand, the tubes of sterile milk which had been exposed under the cows' flanks for 20 minutes all curdled, and each showed the presence of *all three species of lactic bacteria*.



By the results of this second series of experiments the conclusion drawn from the first set in the previous year was verified and emphasized. Milk drawn directly from the cow, at least in this stable, never contained the lactic bacteria. All of the three common species of lactic organisms are a contamination which gets into the milk during the milking or subsequently.

#### THIRD SERIES OF EXPERIMENTS.

It was deemed wise to confirm the results obtained in the preceding experiments by a study of the udders of cows, in order to demonstrate if possible the presence or absence of any of the three common lactic bacteria in the udder. Ward\* and others have made investigations of a similar character, but apparently none of those who have previously made examinations of cows' udders have found organisms which agree with either of the three known types of lactic bacteria of this region. Inasmuch, however, as previous investigators made no especial attempt to determine the presence of normal lactic organisms, it was thought necessary to repeat the experiments, and, if possible, verify their conclusions. If the observations reported in the previous part of this paper are correct, we should certainly not expect to find the normal lactic bacteria in the udder of cows. If, on the other hand, either of the three forms were found in the udders, it would manifestly be impossible to obtain milk by any normal precautions which would be free from lactic germs.

Only two cows were available for examination in the course of these experiments. These two cows were from the same herd in which the rest of the experiments had been carried on. They had been condemned to slaughter because of reaction to tuberculin. Briefly, the study of these two specimens was as follows:

*Cow No. 1.*—In the case of this cow the autopsy showed the presence of no tuberculosis so far as could be seen, but only a thrombus of the heart due to a general infection. The udder was apparently in a perfectly normal condition, presenting neither tubercular lesions nor inflammation. The cow was a

\* N. Y. Cornell Sta. Bul., 178.



new milch cow, and the milk was of good flavor and consistency. Previous to the slaughter the cow had not been milked, a precaution taken to prevent the removal of any organisms that might chance to be in the milk ducts.

The udder was taken from the cow immediately after slaughter and brought to the laboratory, where it was examined and tested for bacteria. The examination was made within half an hour after the removal of the udder from the cow. All instruments used were sterilized. The skin of the udder was reflexed and a dorso-ventral incision made through the glandular portion of the milk system and extending into the duct. From several portions of the udder inoculations were made with a sterile platinum needle directly into a variety of culture media, care being taken not to allow the milk of one portion of the udder to come in contact with the other portions. Inoculations were made in sterile milk, in serum tubes, upon agar slants, and in blue litmus-gelatin tubes. All culture tubes were then set aside, some at ordinary temperatures and others at 37° C.

The results of inoculations were as follows: The milk tubes that had been placed at 37° C. curdled in 36 hours with an acid reaction. Milk in tubes placed at 22° C. also developed an acid reaction, but did not curdle unless heated, and a little clear whey separated from it. The gelatin plates showed the presence of only a single species of bacteria, which was an acid producer and is described below. The other culture tubes placed at different temperatures showed, however, the presence of three species of bacteria, one of which was the same as that shown by the gelatin plates; the other two organisms had never been found in milk and were regarded as contaminations. They were not acid organisms, and no especial attention was paid to them.

*Cow No. 2.*—In this case the autopsy showed a few mesenteric glands infected with tuberculosis and a single nodule in the liver. The lungs and udder appeared perfectly normal. The milk was good, and showed nothing that would indicate any abnormal condition of the udder. The udder was treated as in the previous case, but the inoculations were made in a different way. After reflexing the skin the various surfaces of the udder were burned with a hot knife, a stab was then

made by a long sterile needle through the flesh into various portions of the udder, and cultures were made as in the previous experiments. The udder was then opened by a dorso-ventral incision as before, and other cultures made. Inoculations were made as before into a variety of culture media, and these were kept at 22° C. and 37° C. for examination.

As before, the milk tubes at 37° C. curdled in 24-36 hours with an acid reaction, while those remaining at 22° did not curdle, though they became acid and curdled upon boiling. The plate cultures, as before, showed the presence of but one species of bacterium which produced perfectly characteristic colonies. The agar tubes and blood serum tubes in this experiment also showed the presence of this organism alone. In short, all of the inoculations made from this second animal agree in indicating the presence of one species of bacterium and one only. The organism found was identical with the one found in the first cow and may, therefore, be regarded as a common udder bacterium in the cows of this particular herd.

The organism in question is doubtless identical with one found many times by Conn in milk, and numbered by him in his Classification of Dairy Bacteria\* as No. 60, and named *M. acidi lactici* I. This organism he regards as belonging to a group to which belong also Nos. 113, 104, 78, and 58, these different varieties forming a group of coccus forms distinctively characteristic of milk. Apparently also the organism is the same as the micrococci found by Ward in his work on the udder and described by him. The description which he gives is not quite identical with that given by Conn, but the differences are so slight as to indicate that they are probably identical organisms.

The organism in question was tested in the laboratory by the ordinary culture means and found to have the following general characteristics:

DESCRIPTION OF ORGANISM FOUND IN TWO UDDERS.

*Morphology*—Coccus usually found in pairs from .6 to 1μ in diameter.

*Motility*—None.

*Temperature*—Grows readily at ordinary temperature and rapidly at 37° C.

*Mica plate*—Not determined.

\* See Report Storrs Station, 1899, pp. 13-68.

*Gelatin plate*—Colonies on the surface are raised into beads varying in color from white to yellow, smooth edge and shiny. In the litmus gelatin there is a halo of red which is not very deep.

*Gelatin stab*—Quite abundant needle growth which is beaded. The surface is rough, irregular and abundant, of an orange tint.

*Potato*—Not determined.

*Agar slant*—Irregular growth, smooth and highly reflecting, varying from white to yellow.

*Blood serum*—Characters the same as on agar.

*Milk*—At 37° C. curdles in 24 to 36 hours with a hard curd with little whey. Not strongly acid. At 20° C. milk does not curdle, but is acid. This will curdle on heating.

*Bouillon*—Becomes cloudy after 24 hours, and after several days deposits a sediment.

The effect of this organism on milk is such as to produce an acid reaction without curdling the milk. Moreover, as indicated by the previous experiments and also by the experiments of Conn and Esten, this organism is not one which increases to any considerable extent in milk during its souring, and it is certainly not one of the species that contributes materially to the normal souring of milk in this locality. Apparently this organism then is not one which is of any especial significance in the souring or keeping property of milk. Whether it has any significance in regard to the healthful properties of the milk has not been determined. In soured milk or in fully ripened cream it appears to have totally disappeared under the action of the other organisms which have multiplied rapidly. It is therefore probable that this organism has nothing to do with the souring of milk; and it therefore follows that the bacteria in the udder have no important relation to the problem of keeping milk.

#### SUMMARY.

1. *The experiments reported here, together with those in the article by Conn and Esten, indicate that in this region, at least, the souring of milk and cream is produced primarily by three species of bacteria: B. acidi lactici, B. acidi lactici II., and B. lactis aerogenes. Of these, the first is the one that contributes most largely to the production of lactic acid and is apparently identical with the species described by Hueppe, Marpmann, Esten and others.*

2. *When milk is drawn from the cows in such a manner as to exclude from it dirt and dust from the air, the stable, and the cow, such milk may contain none of the organisms capable of producing a normal souring of milk. In the large herd of 70 cows experimented upon this was seen to be the case with each cow.*

3. *The three normal species of lactic bacteria are a secondary contamination of the milk from some external source.*

4. *In the dairy experimented upon, while all three species of lactic bacteria were present in the air, the *B. acidi lactici* I. appear to be present in the smallest numbers, although apparently so abundant that all samples of milk if exposed for a short time will become infected with it.*

5. *None of the three species of lactic bacteria was found in the udder of the cows examined, which is in accordance with the results of others who have examined the udders of cows.*

6. *The udders of the cows examined contained a single species of micro-organism, apparently identical with that found by Ward in the udder, and by Conn found very commonly present in milk.*

7. *The invasion of the milk by the udder bacteria is of no great importance so far as concerns the keeping quality of milk. Out of three hundred tests made of fore-milk drawn directly from the udder into sterile vials, only about 2 per cent. contained the normal acid bacteria, and these were all contaminations from the outside.*

## ANALYSES OF FODDERS AND FEEDING STUFFS.

BY A. P. BRYANT.

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In connection with the investigations reported in this publication, there have been made analyses of about 60 samples of crops from the field experiments with fertilizers, and 50 samples of various fodders and feeding stuffs used in the dairy herd tests. In addition to these, analyses were made of not far from 300 samples of food materials, feces, and urine in connection with the metabolism and digestion experiments with men, and 25 determinations of nitrogen in crops grown in the pot experiments. The methods of analysis were those recommended by the Association of Official Agricultural Chemists\* with such minor modifications as have been found of advantage in this laboratory.

The analyses made in connection with the experiments with men will be published with the other details of the investigations.† The proportions of nitrogen in the crops from the pot experiments will be given in the discussion of those experiments. The descriptions and analyses of the materials from the field experiments and dairy herd tests are given on the following pages of this Report. The analyses of the crops from the field experiments, given in Table 20, show only the percentages of water, dry matter, nitrogen, and protein in the fresh substance, and of nitrogen and protein in the water-free material, as these were the only determinations necessary for the purpose of the experiments. In the feeding tests with dairy herds, more complete analyses of the fodders and feeding stuffs were required. These are given for the water-free material in Table 22, and for the fresh substance in Table 21. In all these tables two sets of averages are given, the first being the averages of analyses here published for the first time, while the second are the averages of all analyses of similar materials thus far made in this laboratory, including those here reported.

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\* U. S. Dept. Agr., Division of Chemistry, Bul. 46, revised.

† See article on Results of Metabolism Experiments beyond.



According to the usual custom, protein has been given as total nitrogen multiplied by the factor 6.25, on the assumption that protein contains 16 per cent. of nitrogen. As has been repeatedly pointed out, however, this factor is only approximately correct, for the reasons given on page 39 of the present Report.

#### TESTS FOR NITRATES IN FIELD CROPS.

In the experiments made by the Station on the effects of nitrogenous fertilizers upon the composition of field crops, it has been found that in such crops as corn and various grasses, the percentage of nitrogen in the plants increased as the nitrogen in the fertilizers was increased. According to the usual method of estimating the protein of the plant from the amount of nitrogen determined, the experiments thus apparently indicated that the increasing of the nitrogen in the fertilizers increased the proportion of nitrogenous compounds (protein) in the crops. The question arose whether the total increase in the nitrogen of the plant actually represented an increase in protein, or whether some of the nitrogen of the fertilizer, taken up by the plant in the form of nitrates, was retained in its tissues as such without being transformed into organic nitrogenous compounds of the plant. This has sometimes been found to be the case. Tobacco frequently contains considerable quantities of nitrates, and the quantity present has been found to increase with the increase of nitrogen in the fertilizers.\* Large quantities of nitrates have also been found in corn grown on especially rich soil.† It might thus be possible that the corn and grasses grown on the plots or in the pots supplied with large quantities of nitrogenous fertilizers would contain appreciable amounts of nitrates. To get some light upon this question some of the plants grown in the Station plot and pot experiments were tested for the presence of nitrates.

With one exception all the samples tested were from the crops grown on plots or in pots supplied with the "full ration" of nitrogen, that is, nitrogen at the rate of 75 pounds per acre. The samples taken from the pot experiments were all from the pots with nitrate of soda; those from the plot experiments were

\* See, for example, investigations reported in Conn. Sta. Rpt. 1896, pp. 322-333; also North Carolina Sta. Bul. 122.

† A striking case has been reported in Kansas Sta. Bul. 49.

part from the nitrate of soda and part from the sulphate of ammonia plots. One sample of corn stover was from the crop grown on a plot supplied with the mineral fertilizers alone.

The results of the tests are given in the following table.

TABLE 19.

*Amount of nitric nitrogen found in different crops.*

Laboratory No.	MATERIAL.	Kind of experiment and amount of nitrogen used.	Total nitrogen in partially dried material.	Nitric nitrogen in partially dried material.	Proportion of nitric to total nitrogen.
			%	%	%
6200	Orchard grass, - -	Pot exp'ts, full ration, -	2.56	.075	.029
6201	Orchard grass, - -	Pot exp'ts, full ration, -	2.41	.100	.041
6202	Orchard grass, - -	Pot exp'ts, full ration, -	2.46	.075	.031
6203	Orchard grass, - -	Pot exp'ts, full ration, -	2.41	.100	.041
6216	Hungarian grass, -	Pot exp'ts, full ration, -	2.12	.100	.047
6217	Hungarian grass, -	Pot exp'ts, full ration, -	2.16	.075	.035
6218	Hungarian grass, -	Pot exp'ts, full ration, -	2.07	.100	.048
6219	Hungarian grass, -	Pot exp'ts, full ration, -	2.25	.100	.044
6248	Orchard grass, rowen,	Pot exp'ts, full ration, -	1.11	—	—
6249	Orchard grass, rowen,	Pot exp'ts, full ration, -	1.06	—	—
6250	Orchard grass, rowen,	Pot exp'ts, full ration, -	1.18	—	—
6251	Orchard grass, rowen,	Pot exp'ts, full ration, -	1.10	—	—
6257	Silage corn, - -	Plot exp'ts, full ration, -	1.38	.025	.018
6260	Silage corn, - -	Plot exp'ts, full ration,*	1.30	.013	.010
6268	Cow pea fodder, -	Plot exp'ts, full ration, -	2.64	.025	.009
6270	Cow pea fodder, -	Plot exp'ts, full ration,*	2.75	.013	.005
6278	Corn stover, - -	Plot exp'ts, full ration, -	1.28	.013	.010
6281	Corn stover, - -	Plot exp'ts, full ration,*	1.50	.013	.009
6288	Corn—seeds, - -	Plot exp'ts, full ration, -	1.13	—	—
6291	Corn—seeds, - -	Plot exp'ts, full ration,*	.93	—	—
6308	Corn—seeds, - -	Plot exp'ts, full ration, -	1.69	—	—
6311	Corn—seeds, - -	Plot exp'ts, full ration,*	1.63	—	—
6318	Corn—seeds, - -	Plot exp'ts, full ration, -	1.75	—	—
6321	Corn—seeds, - -	Plot exp'ts, full ration,*	1.50	—	—
6274	Corn stover, - -	Plot exp'ts, no nitrogen,	.83	—	—

\* In these experiments the nitrogen was supplied in sulphate of ammonia, in the others in nitrate of soda.

In making these tests, the colorimetric method devised by Hooker and described by Wiley\* was employed, with but little modification of the procedure. The basis of this method is the blue coloration produced by small quantities of nitrates in a sulphuric acid solution of diphenylamine, the intensity of the color differing with differences in the quantity of nitrates present. With a little care this method can be used to obtain

\* Principles and Practice of Agricultural Analysis, Vol. I., pp. 548-554.

results approximately accurate. The tests were made in aqueous extracts of the different samples. The amounts of nitrates present in these extracts were estimated by comparing the intensity of the color produced in the aqueous extract with that produced in a standard solution containing a known amount of nitrate.

The intensity of the blue color produced in the extracts was affected somewhat by the presence of organic coloring matters. The extracts of the grasses were highly colored, some being almost opaque. The effect of these coloring matters was modified to some extent by diluting the extracts.

There was a larger proportion of nitrates present in the samples from the pot experiments than in those from the plot experiments; the comparison, however, is between different crops. It may be possible that there was less leaching of nitrogen from the soil in the pot experiments, but on this point these investigations furnish no evidence.

While the first cutting of orchard grass in the pot experiments contained appreciable amounts of nitrates, the rowen from the same pots contained none.

The corn seeds, as was to be expected, gave no tests for nitrates. No nitrates were found in the corn stover grown on the plots supplied with the mineral fertilizers without nitrogen.

#### DESCRIPTION OF SAMPLES.

The analyses given in Table 20 are those of the field crops grown in the plot experiments of 1900 reported on pages 34-60 of the present Report. The conditions under which the samples described below were grown, is there given. The analyses given in Table 21 are those of the various fodders and feeding stuffs used in feeding tests with dairy herds conducted by the Station, as described on later pages.

#### GREEN FODDERS.

*No. 6261. Ensilage corn.*—(Ohio white dent.) Sample of about 150 pounds taken September 18, 1900, from five loads being cut up for the silo; this was thoroughly mixed and sub-sample taken and dried in steam drier. Lower leaves of stalks were somewhat dried, otherwise fodder quite succulent. Ears beginning to glaze or in dough stage.

*Nos. 6262-6271. Cow pea fodder.*—Grown in the special nitrogen experiments of 1900. Samples taken September 21 and 22, 1900. In sampling the crop taken from each plot, large samples of about 25 pounds were taken by

removing small quantities from different parts of the crop as it was being cut up in the ensilage cutter at the silo. Each large sample was thoroughly mixed and a sub-sample was taken, weighed and dried at once in the steam drier.

Nos. 6262 and 6263 were from plots o and oo respectively. The vines were small and yellow; not very succulent; and there were no immature pods and seeds.

Nos. 6264 and 6265 were from plots 6a and 6b respectively. The vines were large and succulent; good color; few immature pods and seeds.

Nos. 6266-6271 were from plots 7-12 respectively. The growth on these plots was similar to that on plots 6a and 6b.

#### ENSILAGE.

*Corn ensilage.*—Used in dairy herd tests. In sampling a considerable amount of the ensilage was thoroughly mixed and sample taken. The samples were believed to be averages of what was fed.

No. 6125 from dairy herd test No. 51. Sample taken December 13, 1899. The crop was well eared and the grain quite hard when harvested.

No. 6171 from dairy herd test No. 55. Sample taken January 31, 1900. The corn was just past the milk stage when harvested.

No. 6181 from dairy herd test No. 57. Sample taken March 8, 1900. The ensilage was from the same lot as No. 6171, but taken about three feet lower in the silo, and seemed more moist.

#### CURED FODDERS.

Nos. 6272-6291. *Stover of white flint corn.*—Grown in the special nitrogen experiments of 1900. The samples of stover were taken October 25-27, 1900, just after the corn was husked and the stover was weighed. In each case the entire crop of stover on each plot was cut into pieces one to two inches long and then thoroughly mixed and sampled. Nos. 6272-6281 were samples of crops grown on the sections at the north ends of the plots and Nos. 6282-6291 on the sections at the south ends.

Nos. 6272 and 6273 were from plots o and oo. The growth on plot o was very light, that on oo a little better. On both plots the stalks were small and slender and pale in color.

Nos. 6274 and 6275 were from plots 6a and 6b. The stalks were rather slender and pale colored.

No. 6276 was from plot 7. The growth was rather irregular, the stalks were slightly pale in color.

No. 6277 was from plot 8. The stalks were quite heavy and dark green in color.

No. 6278 was from plot 9. Stalks not so heavy as on plot 8; dark green in color.

No. 6279 was from plot 10. Heavy growth of stalks; slightly pale in color.

No. 6280 was from plot 11. Stalks heavy and dark green in color.

No. 6281 was from plot 12. Stalks much lighter than on plots 10 and 11; dark green in color.

Nos. 6282 and 6283 were from plots o and oo. Light growth of stalks pale in color.

Nos. 6284 and 6285 were from plots 6a and 6b. Stalks rather slender and pale in color; better on 6b than on 6a.

No. 6286 was from plot 7. Stalks medium heavy; fair in color.

No. 6287 was from plot 8, and No. 6288 from plot 9. Heavy growth of stalks, dark green in color.

No. 6289 was from plot 10. Quite heavy growth of stalks; fair in color.

No. 6290 was from plot 11, and No. 6291 from plot 12. Heavy growth of stalks; dark green in color.

*Corn stover*.—Used in dairy herd tests. In most cases the stover was of good quality. The samples were believed to represent an average of what was being fed. Usually 10–30 pounds was cut up into small pieces, and then thoroughly mixed and sub-sampled.

No. 6134 from dairy herd test No. 52. Sample taken December 27, 1899.

No. 6160 from dairy herd test No. 54. Stover slightly mouldy. Sampled January 24, 1900.

No. 6174 from dairy herd test No. 56. Sample taken February 15, 1900, from lot that had been cut up in December.

No. 6180 from dairy herd test No. 57. Sample taken March 8, 1900, from lot that had been cut up in January.

No. 6185 was used in dairy herd test No. 58. Sample taken March 15, 1900.

*Oat Straw*.—Used in dairy herd tests. Straw of good quality. In sampling, a considerable amount was cut into short pieces, thoroughly mixed and sampled.

No. 6133 from dairy herd test No. 52. Sample taken December 27, 1899.

No. 6162 from dairy herd test No. 54. Sample taken January 24, 1900.

*Hay of mixed grasses*.—Used in dairy herd tests. In each case the hay was of good quality, had been harvested early and put in the barn in good condition. In taking samples, about 10–30 pounds was cut into small pieces, then thoroughly mixed and sampled.

No. 6124 from dairy herd test No. 51. Sample taken December 13, 1899.

No. 6131 from dairy herd test No. 52. Sample taken December 27, 1899.

No. 6135 from dairy herd test No. 52. Rowen hay, about half timothy and half red-top. Sample taken December 27, 1899.

No. 6161 from dairy herd test No. 54. Rowen hay of mixed grasses and clover. Sample taken January 24, 1900.

No. 6170 from dairy herd test No. 55. Part of this hay was of previous year's crop. Sample taken January 31, 1900.

No. 6173 from dairy herd test No. 56. Hay grown on low land, contained considerable timothy and red-top. Sample taken February 15, 1900.

No. 6179 from dairy herd test No. 57. Sample taken March 8, 1900.

No. 6184 from dairy herd test No. 58. Hay grown on low land. Sample taken March 15, 1900.



*Hungarian hay*.—No. 6132 from dairy herd test No. 52. Hay of good quality, early cut. Sample taken December 27, 1899.

*Oat and pea hay*.—No. 6136 from dairy herd test No. 53. Oat grains nearly ripe, peas succulent when harvested; fodder harvested in good condition. Sample taken January 13, 1900.

#### SEEDS.

*Nos. 6292-6301. Soy bean seed*.—Grown in special nitrogen experiments of 1900. Samples were taken November 13, 1900. In each case the total amount of seed grown on a plot was mixed thoroughly and a sample of about two quarts was taken. This sample was cleaned of dirt, mouldy and broken seeds, and a final sample of one quart jar full was taken and sealed at once.

Nos. 6292 and 6293 were from plots 0 and 00. There was considerable seed not fully developed.

Nos. 6294 and 6295 were from plots 6a and 6b. The seed was well developed and quite uniform.

Nos. 6296-6301 were from plots 7-12 respectively. The seed was similar to that on plots 6a and 6b.

*Nos. 6302-6321. White flint corn (grain)*.—Grown in special nitrogen experiments of 1900. Nos. 6302-6311 were from sections at the north ends of the plots and Nos. 6312-6321 from sections at the south ends. The samples were taken November 21, 1900. In each case the total amount of corn on the plot was shelled, thoroughly mixed and sub-sampled. The sub-sample was cleaned of chaff, dust and mouldy corn, and a final sample of one quart jar full was taken and sealed.

Nos. 6302 and 6303 were from plots 0 and 00. There was a large proportion of "poor" or immature seed.

Nos. 6304 and 6305 were from plots 6a and 6b. Ears were quite well developed; there was slightly more immature corn than on plots 8 and 9.

No. 6306 was from plot 7. The ears were quite well developed. There was about as much immature seed as on plots 6a and 6b.

Nos. 6307-6311 were from plots 8-12 respectively. The ears were well developed and there was very little immature seed. On plot 12 the ears were not as heavy as on plots 10 and 11.

Nos. 6312 and 6313 were from plots 0 and 00. There was a large proportion of poor or immature seed.

Nos. 6314 and 6315 were from plots 6a and 6b. The ears were well developed and there was but little immature seed.

Nos. 6316-6321 were from plots 7-12 respectively. On all these plots the ears were well developed and there was but very little immature seed.

#### MILLING AND BY-PRODUCTS.

The following samples were those of milling products used in the dairy herd tests. The samples were taken in such a way as to represent averages of the different feeds as used during the tests.

Nos. 6121, 6128 and 6177. Wheat bran from dairy herd tests Nos. 51, 52 and 56 respectively.

No. 6122. Wheat middlings from dairy herd test No. 51.

No. 6123. Chicago gluten meal from dairy herd test No. 51.

No. 6126. H. O. standard dairy feed from dairy herd test No. 52.

No. 6127. Provender from dairy herd test No. 52; made up of oats 140 pounds and corn on ear 360 pounds ground together.

Nos. 6129, 6169 and 6175. Buffalo gluten feed from dairy herd tests Nos. 52, 55 and 56 respectively.

No. 6130. Cotton seed meal from dairy herd test No. 52.

No. 6137. Grain mixture from dairy herd test No. 53; made up of 1,000 pounds wheat bran, 400 pounds wheat middlings, 200 pounds cotton seed meal, 125 pounds Chicago gluten meal.

No. 6138. Grain mixture from dairy herd test No. 53; made up of 200 pounds cotton seed meal, 125 pounds Chicago gluten meal, 100 pounds wheat middlings.

No. 6164. Grain mixture from dairy herd test No. 54; made up of 100 pounds cotton seed meal, 125 pounds Chicago gluten meal, 100 pounds wheat middlings.

No. 6165. Grain mixture from dairy herd test No. 54; made up of 100 pounds provender (oats 140 pounds and ear corn 360 pounds ground together), 200 pounds wheat bran, 125 pounds Chicago gluten meal.

No. 6166. Mixed feed from dairy herd test No. 55; apparently a mixture of wheat bran and middlings.

No. 6167. Provender from dairy herd test No. 55; made up of 600 pounds oats and 900 pounds corn on cob ground together.

No. 6168. Ground wheat from dairy herd test No. 55.

No. 6172. Grain mixture from dairy herd test No. 55; made up of 190 pounds "mixed feed," 160 pounds Chicago gluten meal, and 150 pounds provender.

No. 6176. Corn and cob-meal from dairy herd test No. 56.

No. 6178. Atlantic gluten meal, analyzed, but not used in dairy herd tests.

No. 6182. Grain mixture from dairy herd test No. 57; made up of 200 pounds wheat feed, 200 pounds Buffalo gluten feed, 200 pounds provender, and 150 pounds cotton seed meal.

No. 6183. Grain mixture from dairy herd test No. 57; made up of 200 pounds Buffalo gluten feed and 200 pounds cotton seed meal.

No. 6186. Grain mixture from dairy herd test No. 58; made up of 200 pounds wheat bran, 200 pounds corn and cob meal, and 200 pounds cream gluten meal.

No. 6187. Grain mixture from dairy herd test No. 58; made up of 200 pounds cream gluten meal and 100 pounds Buffalo gluten feed.

TABLE 20.

*Composition of samples of field crops grown with different fertilizers in the plot experiments of 1900.*

[Averages of analyses here given together with those of former years.]

Laboratory No.	MATERIAL.	IN WATER-FREE SUBSTANCE.		IN FRESH SUBSTANCE.			
		Nitrogen.	Protein. N. $\times$ 6.25.	Water.	Dry matter.	Nitrogen.	Protein. N. $\times$ 6.25.
		%	%	%	%	%	%
6262	Cow pea fodder, - -	2.92	18.25	80.4	19.6	0.6	3.6
6263	Cow pea fodder, - -	2.93	18.31	80.1	19.9	0.6	3.7
6264	Cow pea fodder, - -	2.95	18.44	81.8	18.2	0.5	3.4
6265	Cow pea fodder, - -	2.89	18.06	81.5	18.5	0.5	3.3
6266	Cow pea fodder, - -	3.44	21.50	80.7	19.3	0.7	4.2
6267	Cow pea fodder, - -	2.74	17.13	79.0	21.0	0.6	3.6
6268	Cow pea fodder, - -	2.88	18.00	80.4	19.6	0.6	3.5
6269	Cow pea fodder, - -	2.78	17.38	82.1	17.9	0.5	3.1
6270	Cow pea fodder, - -	3.00	18.75	81.0	19.0	0.6	3.6
6271	Cow pea fodder, - -	2.97	18.56	83.6	16.4	0.5	3.1
	Average (10), - -	2.95	18.44	81.1	18.9	0.6	3.5
	Average all analyses, -	2.96	18.52	82.8	17.2	0.5	3.2
6272	Corn stover, - - -	1.08	6.79	15.0	85.0	0.9	5.8
6273	Corn stover, - - -	1.34	8.37	11.3	88.7	1.2	7.4
6274	Corn stover, - - -	.92	5.75	16.4	83.6	0.8	4.8
6275	Corn stover, - - -	.94	5.90	13.6	86.4	0.8	5.1
6276	Corn stover, - - -	.88	5.50	15.6	84.4	0.7	4.6
6277	Corn stover, - - -	1.12	7.00	17.2	82.8	0.9	5.8
6278	Corn stover, - - -	1.36	8.50	19.7	80.3	1.1	6.8
6279	Corn stover, - - -	.98	6.13	16.7	83.3	0.8	5.1
6280	Corn stover, - - -	1.53	9.56	15.7	84.3	1.3	8.1
6281	Corn stover, - - -	1.64	10.25	24.5	75.5	1.2	7.8
6282	Corn stover, - - -	1.17	7.31	13.1	86.9	1.0	6.4
6283	Corn stover, - - -	1.40	8.75	14.9	85.1	1.2	7.4
6284	Corn stover, - - -	.92	5.75	22.2	77.8	0.7	4.5
6285	Corn stover, - - -	.81	5.06	18.2	81.8	0.7	4.1
6286	Corn stover, - - -	.89	5.56	21.2	78.8	0.7	4.4
6287	Corn stover, - - -	.99	6.19	20.1	79.9	0.8	5.0
6288	Corn stover, - - -	1.22	7.63	24.8	75.2	0.9	5.7
6289	Corn stover, - - -	.78	4.88	25.7	74.3	0.6	3.6
6290	Corn stover, - - -	.91	5.69	30.0	70.0	0.6	3.9
6291	Corn stover, - - -	.98	6.13	24.9	75.1	0.7	4.6
	Average (20), - -	1.09	6.84	19.0	81.0	0.9	5.5
	Average all analyses, -	1.06	6.60	37.6	62.4	0.7	4.1
6292	Soy bean seed, - -	7.37	46.07	11.0	89.0	6.6	41.0
6293	Soy bean seed, - -	7.63	47.69	10.3	89.7	6.8	42.8
6294	Soy bean seed, - -	6.91	43.19	9.4	90.6	6.3	39.1
6295	Soy bean seed, - -	7.16	44.75	10.3	89.7	6.4	40.1
6296	Soy bean seed, - -	7.45	46.57	11.2	88.8	6.6	41.3
6297	Soy bean seed, - -	7.42	46.38	11.0	89.0	6.6	41.3
6298	Soy bean seed, - -	7.48	46.75	10.7	89.3	6.7	41.8
6299	Soy bean seed, - -	7.23	45.19	11.1	88.9	6.4	40.2
6300	Soy bean seed, - -	7.22	45.13	11.0	89.0	6.4	40.1
6301	Soy bean seed, - -	7.27	45.44	12.2	87.8	6.4	39.9
	Average (10), - -	7.31	45.72	10.8	89.2	6.5	40.8
	Average all analyses (55), -	6.63	41.45	8.7	91.3	6.0	37.8

TABLE 20.—(Continued.)

Laboratory No.	MATERIAL.	IN WATER-FREE SUBSTANCE.		IN FRESH SUBSTANCE.			
		Nitrogen.	Protein. N. $\times$ 6.25.	Water.	Dry mater.	Nitrogen.	Protein. N. $\times$ 6.25.
		%	%	%	%	%	%
6302	White flint corn, - -	1.71	10.69	10.1	89.9	1.5	9.6
6303	White flint corn, - -	1.67	10.44	11.6	88.4	1.5	9.3
6304	White flint corn, - -	1.59	9.94	11.2	88.8	1.4	8.8
6305	White flint corn, - -	1.63	10.19	12.4	87.6	1.4	8.9
6306	White flint corn, - -	1.66	10.38	9.6	90.4	1.5	9.4
6307	White flint corn, - -	1.73	10.81	7.3	92.7	1.6	10.0
6308	White flint corn, - -	1.87	11.69	9.8	90.2	1.7	10.6
6309	White flint corn, - -	1.61	10.06	10.1	89.9	1.5	9.1
6310	White flint corn, - -	1.75	10.94	9.5	90.5	1.6	9.9
6311	White flint corn, - -	1.80	11.25	9.3	90.7	1.6	10.2
6312	White flint corn, - -	1.59	9.94	9.2	90.8	1.4	9.0
6313	White flint corn, - -	1.83	11.44	6.4	93.6	1.7	10.7
6314	White flint corn, - -	1.52	9.50	10.8	89.2	1.4	8.5
6315	White flint corn, - -	1.55	9.69	10.7	89.3	1.4	8.6
6316	White flint corn, - -	1.57	9.81	10.0	90.0	1.4	8.8
6317	White flint corn, - -	1.85	11.56	8.8	91.2	1.7	10.6
6318	White flint corn, - -	1.94	12.13	9.6	90.4	1.8	10.9
6319	White flint corn, - -	1.64	10.25	8.7	91.3	1.5	9.4
6320	White flint corn, - -	1.75	10.94	10.8	89.2	1.6	9.8
6321	White flint corn, - -	1.70	10.63	11.5	88.5	1.5	9.4
	Average (20), - -	1.70	10.61	9.9	90.1	1.5	9.6
	Average all analyses (233)	1.75	10.94	17.3	82.7	1.5	9.1

TABLE 21.

*Composition of fodders and feeding stuffs analyzed 1899-1900, calculated to water content at time of taking sample.*

Lab. No.	FEEDING STUFFS.	Water.	Protein.	Fat.	Nitrogen-free extract.	Fiber.	Ash.	Fuel value per lb.
		%	%	%	%	%	%	Cal.
<i>Green fodders.</i>								
6261	Ensilage, corn, - - -	69.7	2.5	1.2	18.1	6.8	1.7	560
	Average all analyses (3), -	71.9	2.3	1.1	17.0	6.1	1.6	520
<i>Cured fodders.</i>								
6134	Corn stover, - - -	16.5	4.8	1.5	40.3	29.4	7.5	1450
6160	Corn stover, - - -	23.6	4.4	1.1	38.6	26.7	5.6	1340
6174	Corn stover, - - -	18.8	4.5	1.8	39.3	29.2	6.4	1435
6180	Corn stover, - - -	16.5	5.2	2.0	40.7	29.3	6.3	1485
6185	Corn stover, - - -	9.6	7.0	2.5	47.9	26.2	6.8	1615
	Average (5), - - -	17.0	5.2	1.8	41.3	28.2	6.5	1465
	Average all analyses (205),	39.5	3.8	1.2	30.9	20.5	4.1	1080
6133	Oat straw, - - -	13.5	3.3	2.5	39.3	36.3	5.1	1575
6162	Oat straw, - - -	13.7	3.8	2.8	43.1	31.9	4.7	1585
	Average (2), - - -	13.6	3.5	2.7	41.2	34.1	4.9	1580
	Average all analyses (4), -	12.9	3.3	2.4	40.3	35.9	5.2	1580
6124	Hay, mixed grasses, - -	17.5	5.9	2.1	44.1	25.8	4.6	1500
6131	Hay, mixed grasses, - -	13.2	7.0	2.6	44.8	27.2	5.2	1580
6161	Hay, mixed grasses, - -	11.0	9.4	4.2	43.9	26.4	5.1	1660
6170	Hay, mixed grasses, - -	6.8	7.2	2.9	47.5	31.0	4.6	1715
6173	Hay, mixed grasses, - -	10.1	6.7	2.9	48.5	26.9	4.9	1650
6179	Hay, mixed grasses, - -	11.2	6.3	2.9	44.1	31.4	4.1	1645
6184	Hay, mixed grasses, - -	8.2	8.4	3.6	47.5	26.6	5.7	1685
	Average (7), - - -	11.1	7.3	3.0	45.8	27.9	4.9	1635
	Average all analyses (49),	11.7	8.0	2.9	44.1	28.1	5.3	1615
6135	Hay, rowen, - - -	13.8	14.3	4.4	38.6	23.2	5.7	1600
6163	Hay, rowen, - - -	11.8	12.8	3.1	37.6	27.0	7.7	1570
	Average (2), - - -	12.8	13.6	3.7	38.1	25.1	6.7	1585
	Average all analyses (17),	13.1	14.0	3.7	38.3	24.4	6.5	1580
6132	Hay, Hungarian, - - -	12.3	9.6	2.3	35.8	32.4	7.6	1545
	Average all analyses (34),	16.4	8.2	3.2	43.7	22.9	5.6	1525
6136	Hay, oat and pea, - -	12.1	11.1	2.0	40.8	26.3	7.7	1540
<i>Ensilage.</i>								
6125	Corn ensilage, - - -	73.6	2.0	.7	15.2	7.1	1.4	480
6171	Corn ensilage, - - -	70.2	1.9	.9	18.8	6.7	1.5	545
6181	Corn ensilage, - - -	77.4	1.3	.8	13.0	6.5	1.0	420
	Average (3), - - -	73.7	1.7	.8	15.7	6.8	1.3	485
	Average all analyses (24),	74.5	2.0	.9	14.9	6.3	1.4	470
<i>Milling and By-Products.</i>								
6129	Buffalo gluten feed, - -	8.4	23.9	3.4	54.6	6.6	3.1	1725
6169	Buffalo gluten feed, - -	8.2	24.2	2.4	54.8	8.5	1.9	1730
6175	Buffalo gluten feed, - -	10.8	25.7	3.6	50.3	7.6	2.0	1705
	Average (3), - - -	9.2	24.6	3.1	53.2	7.6	2.3	1720
	Average all analyses (12),	8.9	23.9	3.2	51.0	6.4	1.7	1860



TABLE 21.—(Continued.)

Lab. No.	FEEDING STUFFS.	Water.	Protein.	Fat.	Nitrogen-free extract.	Fiber.	Ash.	Fuel value per lb.
	<i>Milling and By-Products.</i>	%	%	%	%	%	%	Cal.
6123	Chicago gluten meal, -	8.7	36.9	2.3	48.9	2.2	1.0	1735
	Average all analyses (14),	8.8	36.7	5.6	45.6	2.5	1.0	1810
6176	Corn and cob meal, -	16.5	7.9	5.0	67.3	1.7	1.6	1640
	Average all analyses (19),	13.0	9.0	4.2	68.4	3.3	1.5	1680
6130	Cotton seed meal, -	7.8	48.1	10.0	22.9	4.7	6.5	1830
	Average all analyses (22),	7.1	44.5	11.7	25.7	4.3	6.7	1880
6121	Wheat bran, - - -	8.8	16.9	5.3	58.5	5.8	4.7	1735
6128	Wheat bran, - - -	9.8	14.4	5.0	51.4	12.6	6.8	1670
6177	Wheat bran, - - -	11.5	15.3	4.4	51.5	11.3	6.0	1640
	Average (3), - - -	10.0	15.5	4.9	53.8	9.9	5.8	1680
	Average all analyses (49),	9.7	16.9	5.0	53.4	9.4	5.6	1695
6122	Wheat middlings, -	9.3	16.7	4.8	51.1	11.6	6.5	1680
	Average all analyses (17),	10.2	18.2	5.1	56.0	6.3	4.1	1710
6178	Atlantic gluten meal, -	8.7	38.0	2.2	47.5	2.4	1.2	1725
6126	H. O. standard dairy feed, -	8.2	17.9	4.4	53.8	12.0	3.7	1745
6168	Ground wheat, - - -	9.0	18.0	5.0	56.3	7.0	4.7	1725
6127	Provender, - - - -	13.9	8.5	4.2	64.3	7.3	1.8	1665
6137	Grain mixture, - - -	10.5	20.7	5.2	49.0	8.9	5.7	1880
6138	Grain mixture, - - -	9.5	36.4	7.9	38.1	4.2	3.9	1790
6164	Grain mixture, - - -	9.5	34.7	6.6	41.9	3.5	3.8	1765
6165	Grain mixture, - - -	10.9	20.2	4.6	52.9	7.7	3.7	1695
6166	Mixed wheat feed, - -	9.8	16.2	4.9	56.9	7.0	5.2	1695
6167	Provender, - - - -	12.5	9.6	5.3	67.6	2.9	2.1	1715
6172	Grain mixture, - - -	10.2	19.6	4.3	55.6	6.6	3.7	1705
6182	Grain mixture, - - -	12.4	25.6	5.1	48.3	4.6	4.0	1675
6183	Grain mixture, - - -	8.6	40.1	6.8	34.5	5.2	4.8	1770
6186	Grain mixture, - - -	13.1	19.6	3.2	57.8	3.8	2.5	1645
6187	Grain mixture, - - -	9.8	29.4	2.3	53.1	3.8	1.6	1705

TABLE 22.

*Composition of water-free substance of fodders and feeding stuffs analyzed, 1899-1900.*

Lab. No.	FEEDING STUFFS.	Protein.	Fat.	Nitrogen-free extract.	Fiber.	Ash.	Fuel value per lb.
		%	%	%	%	%	Cal.
<i>Green fodders.</i>							
6261	Ensilage, corn, - -	8.35	3.98	59.80	22.32	5.55	1850
	Av. all analyses (3),	<b>8.39</b>	<b>3.87</b>	<b>60.69</b>	<b>21.64</b>	<b>5.41</b>	<b>1850</b>
<i>Cured fodders.</i>							
6134	Corn stover, - -	5.69	1.78	48.25	35.25	9.03	1735
6160	Corn stover, - -	5.76	1.43	50.57	34.91	7.33	1755
6174	Corn stover, - -	5.56	2.26	48.34	36.00	7.84	1765
6180	Corn stover, - -	6.18	2.36	48.78	35.07	7.61	1775
6185	Corn stover, - -	7.74	2.80	52.93	29.03	7.50	1785
	Average (5), - -	<b>6.19</b>	<b>2.13</b>	<b>49.77</b>	<b>34.05</b>	<b>7.86</b>	<b>1765</b>
	Av. all analyses (205),	<b>6.37</b>	<b>2.01</b>	<b>51.11</b>	<b>33.81</b>	<b>6.70</b>	<b>1785</b>
6133	Oat straw, - - -	3.77	2.93	45.49	41.96	5.85	1820
6162	Oat straw, - - -	4.48	3.21	49.91	36.93	5.47	1835
	Average (2), - -	<b>4.13</b>	<b>3.07</b>	<b>47.70</b>	<b>39.44</b>	<b>5.66</b>	<b>1825</b>
	Av. all analyses (4),	<b>3.85</b>	<b>2.80</b>	<b>46.25</b>	<b>41.17</b>	<b>5.93</b>	<b>1815</b>
6124	Hay, mixed grasses, -	7.20	2.55	53.45	31.26	5.54	1815
6131	Hay, mixed grasses, -	8.12	2.94	51.62	31.29	6.03	1815
6161	Hay, mixed grasses, -	10.52	4.74	49.32	29.64	5.78	1865
6170	Hay, mixed grasses, -	7.78	3.11	51.00	33.21	4.90	1840
6173	Hay, mixed grasses, -	7.45	3.22	53.98	29.89	5.46	1835
6179	Hay, mixed grasses, -	7.04	3.31	49.63	35.40	4.62	1855
6184	Hay, mixed grasses, -	9.13	3.95	51.74	28.95	6.23	1835
	Average (7), - -	<b>8.18</b>	<b>3.40</b>	<b>51.53</b>	<b>31.38</b>	<b>5.51</b>	<b>1840</b>
	Av. all analyses (49),	<b>9.01</b>	<b>3.31</b>	<b>49.90</b>	<b>31.80</b>	<b>5.98</b>	<b>1825</b>
6135	Hay, rowen, - -	16.56	5.11	44.83	26.99	6.60	1860
6163	Hay, rowen, - -	14.45	3.58	42.64	30.60	8.73	1780
	Average (2), - -	<b>15.50</b>	<b>4.34</b>	<b>43.74</b>	<b>28.75</b>	<b>7.67</b>	<b>1820</b>
	Av. all analyses (17),	<b>16.11</b>	<b>4.25</b>	<b>44.06</b>	<b>28.10</b>	<b>7.48</b>	<b>1820</b>
6132	Hay, Hungarian, -	10.91	2.65	40.84	36.91	8.69	1760
	Av. all analyses (34),						
6136	Hay, oat and pea, -	12.62	2.29	46.48	29.88	8.73	1750
<i>Ensilage.</i>							
6125	Corn ensilage, - -	7.53	2.75	57.57	26.75	5.40	1825
6171	Corn ensilage, - -	6.31	3.08	63.18	22.47	4.96	1840
6181	Corn ensilage, - -	5.99	3.49	57.30	28.81	4.41	1861
	Average (3), - -	<b>6.61</b>	<b>3.11</b>	<b>59.35</b>	<b>26.01</b>	<b>4.92</b>	<b>1842</b>
	Av. all analyses (24),	<b>7.88</b>	<b>3.46</b>	<b>57.20</b>	<b>25.82</b>	<b>5.64</b>	<b>1837</b>
<i>Milling and by-products.</i>							
6129	Buffalo gluten feed, -	26.08	3.67	59.63	7.25	3.37	1884
6169	Buffalo gluten feed, -	26.34	2.60	59.71	9.25	2.10	1882
6175	Buffalo gluten feed, -	28.81	4.05	56.39	8.53	2.22	1915
	Average (3), - -						
	Av. all analyses (12),	<b>26.17</b>	<b>3.96</b>	<b>56.05</b>	<b>6.99</b>	<b>1.83</b>	<b>2037</b>

TABLE 22.—(Continued.)

Lab. No.	FEEDING STUFFS.	Protein.	Fat.	Nitrogen-free extract.	Fiber.	Ash.	Fuel value per lb.
		%	%	%	%	%	Cal.
	<i>Milling and by-products.</i>						
6123	Chicago gluten meal, -	40.40	2.52	53.59	2.35	1.14	1895
	Av. all analyses (14),	<b>40.19</b>	<b>6.02</b>	<b>50.00</b>	<b>2.70</b>	<b>1.10</b>	<b>1980</b>
6176	Corn and cob meal, -	9.41	6.01	80.55	2.08	1.95	1965
	Av. all analyses (19),	<b>11.05</b>	<b>4.78</b>	<b>78.63</b>	<b>3.81</b>	<b>1.73</b>	<b>1940</b>
6130	Cotton seed meal, -	52.13	10.87	24.89	5.07	7.04	1985
	Av. all analyses (22),	<b>47.92</b>	<b>12.57</b>	<b>27.62</b>	<b>4.64</b>	<b>7.26</b>	<b>2020</b>
6121	Wheat bran, - -	18.51	5.77	64.18	6.35	5.19	1900
6128	Wheat bran, - -	15.94	5.58	57.00	13.95	7.53	1855
6177	Wheat bran, - -	17.24	4.91	58.21	12.81	6.80	1850
	Average (3), - -	<b>18.71</b>	<b>5.57</b>	<b>59.08</b>	<b>10.41</b>	<b>6.23</b>	<b>1875</b>
	Av. all analyses (49),	<b>17.23</b>	<b>5.43</b>	<b>59.80</b>	<b>11.04</b>	<b>6.51</b>	<b>1865</b>
6122	Wheat middlings, -	18.47	5.29	56.35	12.76	7.13	1855
	Av. all analyses (17),	<b>20.33</b>	<b>5.64</b>	<b>62.47</b>	<b>6.97</b>	<b>4.59</b>	<b>1910</b>
6178	Atlantic gluten meal, -	41.61	2.44	52.06	2.61	1.28	1895
6126	H. O. Stand'rd dairy f'd,	19.47	4.82	58.56	13.12	4.03	1900
6168	Ground wheat, - -	19.79	5.48	61.91	7.72	5.10	1895
6127	Provender, - -	9.87	4.90	74.66	8.42	2.15	1935
6137	Grain mixture, - -	23.11	5.90	54.72	9.92	6.35	1880
6138	Grain mixture, - -	40.20	8.69	42.11	4.64	4.36	1985
6164	Grain mixture, - -	38.39	7.30	46.26	3.88	4.17	1955
6165	Grain mixture, - -	22.73	5.13	59.38	8.64	4.12	1900
6166	Mixed wheat feed,	17.95	5.40	63.10	7.79	5.76	1880
6167	Grain mixture, - -	11.00	6.00	77.30	3.33	2.37	1955
6172	Grain mixture, - -	21.79	4.76	61.94	7.41	4.10	1900
6182	Grain mixture, - -	29.26	5.77	55.10	5.24	4.63	1910
6183	Grain mixture, - -	43.89	7.38	37.78	5.66	5.29	1935
6186	Grain mixture, - -	22.48	3.72	66.53	4.37	2.90	1895
6187	Grain mixture, - -	32.65	2.55	58.84	4.20	1.76	1880

## RESULTS OF EXPERIMENTS ON THE METABOLISM OF MATTER AND ENERGY IN THE HUMAN BODY.

BY W. O. ATWATER AND F. G. BENEDICT,  
WITH THE CO-OPERATION OF  
A. P. BRYANT, A. W. SMITH AND J. F. SNELL.

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### INTRODUCTION.

In previous Reports of the Station descriptions have been given of the respiration calorimeter and of some of the experiments which have been made therewith.\* In the present article the results of experiments made up to the close of the year 1900 are summarized.†

The ultimate purpose of experiments with men in the respiration calorimeter is the study of some of the fundamental laws of nutrition; and the whole inquiry is based upon the principle that the chemical and physical changes which take place within the body, and to which the general term "metabolism" is applied, occur in obedience to the laws of the conservation of matter and energy.

No one doubts that the law of the conservation of matter governs its metabolism in the living organism, and it is generally believed that the law of the conservation of energy likewise applies to the metabolism of energy. Quantitative determinations of the applications of this law are, however, desirable.

The main subjects proposed for study have been the following:

1. An experimental demonstration of the application of the law of the conservation of energy in the body.

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\* See Reports for 1896 and 1897.

† These experiments are made in coöperation with the U. S. Department of Agriculture. The full details, which would be far too voluminous for an experiment station publication, and which demand a much wider circulation than a report of this Station could give, are being printed in bulletins of the Office of Experiment Stations. The present summary of results is adapted from an extended report to be published as a bulletin of that Office. It is believed that the brevity of this summary is thus justified. W. O. A.

2. The quantities of nutrients and energy metabolized by men under different conditions of rest and muscular and mental exercise.

3. The amounts of material and energy required for internal physiological work, as that of digestion, circulation and respiration.

4. The relation between external muscular work and the nutrients and energy metabolized in its performance. This general problem includes the narrower one of the power of the body as a machine to convert the potential energy of its food and of its previously stored material into muscular energy. Viewed from one standpoint this latter phase of the subject is the same as that to which the expression "The animal body as a prime motor" is frequently applied. From another standpoint it includes the comparison of the animal body with steam engines and other sources of power in respect to the economy with which the energy of fuel is utilized; the fuel in the case of the animal being its food, while in the case of the ordinary machine it is coal, or oil, or wood.

5. The transformations of nutrients and energy in mental work.

6. The capacities of the different classes of nutrients to supply the body with material and energy; the proportions in which they may replace each other in building tissue or yielding energy as heat or as work; and their power to protect each other and the materials of the body from consumption.

7. The kinds and amounts of nutrients required for nourishment of people of different classes and in different conditions in life, the nutritive values of food materials and the fitting of food to the needs of the consumer.

Of the above problems all have been studied to a greater or less extent already except No. 5, which has to do with food and mental work. It is hoped that the study of this latter problem may also be entered upon in the not too distant future. Besides the problems thus detailed a number of others have received attention. Among these are:

8. The digestion and assimilation of food materials.

9. The quantities of carbon dioxide, water, nitrogen, and other materials excreted by the body, as well as the energy given off as heat and as external muscular work under different



conditions of work and rest, together with the rates of elimination at different periods of the day and night. In this connection the respiratory quotient has also been considered.

10. The temperature of the body and its variation during different periods of the day and under different conditions of work, rest and sleep.

11. The need of ventilation in so far as the comfort of the person under experiment is affected by the proportions of carbon dioxid and water in the air in the respiration chamber.

12. Finally a large amount of time, thought and labor has been devoted to the elaboration and testing of the apparatus and methods of experimenting. Five years were thus used before the first actual experiments with men were made.

#### APPARATUS AND METHODS.

The description of the apparatus and of the methods of experimenting with it have been given in considerable detail in former Reports of this Station\* and in publications of the Office of Experiment Stations of the U. S. Department of Agriculture.† It will be sufficient to mention here that the essential features of the apparatus are a chamber seven feet long, four feet wide and six and one-half feet high, furnished with a folding chair, table and bed, and other appliances for physical comfort; apparatus for maintaining, measuring and analyzing a ventilating current of air; arrangements for passing food and drink into the chamber and for removing the solid and liquid excreta, all of which were carefully weighed and sampled for analysis; and devices for determining the heat given off from the body of the man in the chamber, and, in work experiments, a stationary bicycle or other apparatus adapted for the performance of muscular work and for determining the heat equivalent of the muscular work done.

The experimental data include measurements of the income and outgo of both matter and energy in the man's body during an experimental period. The chemical analyses include determinations of the total quantities of the nitrogen, carbon, hydrogen, water and mineral matters of food, drink, and respiratory and excretory products. In obtaining the income and

\* Reports for 1896 and 1897.

† U. S. Dept. Agr., Office of Experiment Stations, Buls. 44, 63 and 69.

outgo of energy, the potential energy of the food eaten and of the solid and liquid excretory products was determined by means of the bomb calorimeter,\* and the kinetic energy given off by the subject was measured by the respiration calorimeter and accessory apparatus.

#### TEST EXPERIMENTS.

Numerous test experiments were made in order to prove whether or not the apparatus and methods gave accurate results. According to one method a known amount of heat was generated electrically within the apparatus and this amount compared with that actually measured. It was found that the differences between the amounts introduced and measured were very small, the average being less than 0.1 per cent. of the quantity of heat generated.

This method gave no indication as to the accuracy of the determinations of carbon dioxide and water. Accordingly, ordinary commercial ethyl alcohol of known strength was burned in the apparatus and the carbon dioxide, water and heat produced were measured in the same way as in the experiments with a man.

A considerable number of these alcohol test experiments were made before the apparatus was used for experiments with a man, and served to show that the determinations of carbon dioxide, water and heat could be made with a high degree of accuracy. Test experiments were also made at frequent intervals during the progress of the experimental investigations with men and served to show whether the apparatus remained in proper condition. In a few instances slight differences between the theoretical amounts of carbon dioxide, water or heat, and those actually found, indicated some slight trouble in the apparatus, which was then remedied.

The details of the various test experiments are published in bulletins of the Office of Experiment Stations of the U. S. Department of Agriculture.† In all, 17 test experiments have been made, in which over 5 liters of ordinary commercial ethyl alcohol have been burned. The total amount of carbon dioxide produced was 19,240 grams, of which 19,207, or 99.8 per cent.,

\* See Reports Storrs Exp. Sta. 1894, p. 135 and 1897, p. 199.

† Buls. 63, 69, and one now in press.

was measured. The total water produced was 12,264 grams, and 12,379 grams, or 100.9\* per cent. was found by analysis. The total heat given off was 64,554 calories and that measured 64,513 calories, or 99.9 per cent. This agreement between the theoretical values and those actually obtained is very close and indicates that the apparatus is an instrument of precision.

#### SCOPE AND PLAN OF THE INVESTIGATIONS.

Between February 1896 and April 1900 inclusive, thirty-four experiments, covering a period of one hundred and fourteen days, were made with the respiration calorimeter. The first four of these, covering a period of twenty-one days, were designated as Nos. 1-4, and the results were published in a previous Report of this Station.† Nine of the twelve days covered by Experiment No. 4, however, really comprised three separate experiments distinguished from each other by difference in occupation of the subject; these for convenience may be designated as 4a, 4b, and 4c. In all these experiments (Nos. 1-4c) the income and outgo of nitrogen and carbon and the income of energy were determined, but the heat given off from the body was not measured. Since they show only the balance of income and outgo of matter they are therefore termed "respiration" experiments.

The results of six other experiments, Nos. 5-10, covering a period of twenty-four days, have also been published.‡ In these and all later experiments the balance of income and outgo of both matter and energy was determined, and they are therefore termed "respiration calorimeter" or "metabolism" experiments.

Of the remaining twenty-four experiments, thirteen, covering a period of forty-one days, are reported in detail in a bulletin of the Office of Experiment Stations of the U. S. Department of Agriculture now in press; the results of the other eleven experiments, covering a period of twenty-eight days, which do

\* Of this excess of water, amounting to nine one-thousandths of the theoretical amount, a part at least may be accounted for by a small leak in a valve through which the air current passed. This source of error, though carefully sought, was not discovered until it had evidently influenced a number of the experiments.

† Report Storrs Exp. Sta. 1896 p. 85. See also U. S. Dept. Agr., Office of Experiment Stations, Bul. 44.

‡ U. S. Dept. Agr., Office of Experiment Stations, Buls. 63 and 69, and Rept. Storrs Exp. Sta. 1897 p. 212.

not form a part of the work of this Station, are soon to be reported in detail elsewhere.

Each metabolism experiment, or series of experiments, was immediately preceded by a digestion experiment of several days duration, in which the subject had the same diet as in the metabolism experiment, the purpose being to bring the body into approximate nitrogen and carbon equilibrium before the beginning of the metabolism experiment proper, and at the same time to secure a more nearly accurate measure of the digestibility of the food. It is almost impossible to obtain exact nitrogen equilibrium, since physiological factors, little understood and not easily controlled, cause more or less fluctuation in the elimination of nitrogen, even when the amount in the diet is uniform. These preliminary digestion experiments were generally of four days duration. Metabolism experiments Nos. 1-4, however, were preceded and followed by digestion periods of three days, while some later experiments were preceded by periods of usually four days, but sometimes more or less. In these preliminary digestion experiments the income and outgo of nitrogen were determined, so that the nitrogen metabolism was measured and in this sense they are metabolism experiments, although they are not here so designated, this term being reserved for experiments in which carbon was also taken into account. There were altogether forty-four digestion and nitrogen metabolism experiments which accompanied or made a part of the thirty-four experiments with the respiration calorimeter. They cover two hundred and one days. Only a small number of the results of these digestion experiments, viz., those belonging to metabolism experiments Nos. 1-4, have yet been published.

The larger part of the seven years in which the work connected with the respiration calorimeter has been going on was devoted to the developing and perfecting of apparatus and experimental methods; yet during the progress of the inquiry a mass of data has been accumulated and results bearing upon a variety of the questions enumerated on pages 97-99 have been obtained.

While it is true that none of these topics can be discussed to the best advantage until the publication of further experiments or without due consideration of the results of research elsewhere,



nevertheless brief reference may be made to a few of them in order to illustrate some of the ways in which the experiments are throwing light upon the fundamental questions of the metabolism of matter and energy in the body and, consequently, upon the general laws of nutrition. It is believed that the data already obtained are sufficient for the discussion of a number of problems. These include (1) food materials supplied and consumed and the difference in the amounts demanded by men at rest and at work, (2) the elimination of water, (3) the elimination of carbon dioxide, (4) the metabolism and elimination of energy, and (5) the income and outgo of energy. These are all topics of general interest. Most of the physiological textbooks and other works bearing on these subjects contain more or less detailed statements concerning them, and in some of them figures are quoted which have been generally accepted. It appears that in many cases these figures rest upon much less experimental evidence than is furnished by the experiments with the respiration calorimeter. In the construction of this apparatus it was possible to make use of the experience and results of earlier investigators, and it seems not unreasonable to suppose that the later methods have yielded results of a character which it was not possible to obtain previously. It is not impossible that future investigations will modify the figures which are here given, and any deductions that may be drawn from them; but it is believed that these results are of sufficient interest to warrant their publication and that they rest upon sufficient experimental evidence to make them useful for some time to come.

#### THE MEN WHO SERVED AS SUBJECTS.

Four different men, E. O., O. F. T., A. W. S., and J. F. S., have served as subjects in these experiments. They were all in excellent health. E. O. was a laboratory assistant, a Swede by birth, who had been a number of years in this country. At the time of the experiments here recorded he was about thirty-two years old and weighed not far from seventy kilograms (154 pounds). A. W. S. was a physicist, a native of New England, twenty-five years old, and weighed about seventy kilograms (154 pounds). O. F. T., a chemist, the subject of but one experiment, No. 3, was also a native of New England,



twenty-four years old and weighed about sixty kilograms (132 pounds). J. F. S., a chemist, was a Canadian by birth, twenty-nine years old, and weighed about sixty-five kilograms (143 pounds).

*Occupation.*—In the rest experiments the subjects were as quiet as they well could be. Practically their only muscular exercise was that involved in dressing and undressing, folding and unfolding the bed, chair, and table, eating, caring for the excretory products, and weighing themselves and the absorbers. They did more or less reading and writing to pass the time. In the work experiments they spent a number of hours, generally eight each day, driving a stationary bicycle.\* It was their purpose to do a reasonable but not excessive amount of work.

#### CLASSIFICATION OF THE EXPERIMENTS.

Experiments Nos. 1 and 2 with E. O., No. 3 with O. F. T. and 4a and 4b with A. W. S. were rest experiments, while 4c with A. W. S. was a work experiment. In none of these experiments were satisfactory determinations made of the outgo of energy. The experimental days began at different hours, and were not divided into six-hour experimental periods, as was done in all experiments after No. 4. Taking into account the seventeen experiments, summarized in the following tables, in which the measurements of the outgo of energy were considered satisfactory, there were seven rest experiments with E. O., covering twenty-five days, one rest experiment with A. W. S., covering three days, and three rest experiments with J. F. S., covering nine days, making altogether eleven rest experiments, covering thirty-seven days. There were also two work experiments with E. O., covering eight days, and four work experiments with J. F. S., covering twelve days, making together six work experiments covering twenty days. Altogether the seventeen rest and work experiments covered a total period of fifty-seven days. In addition eleven rest experiments covering thirty days, and two work experiments covering six days have been completed in connection with a separate investigation.

Each of these experiments is divided into days of twenty-four hours beginning and ending at 7 A. M. Each day is divided into four periods of six hours each; the first two, called day periods, extending from 7 A. M. to 1 P. M. and from 1 P. M. to 7 P. M.; the last two, called night periods, extending from 7 P. M. to 1 A. M. and from 1 A. M. to 7 A. M.

\* Excepting in experiment No. 4b, in which the subject raised and lowered a weight attached to a rope which passed over a pulley.

The chief reason for beginning the experimental day in the morning is found in the belief that the condition of the body in respect to the amounts of material in the alimentary canal and of carbohydrates (glycogen) and oxygen in the tissues and fluids would be more nearly the same, from day to day, at the end of the period of rest and sleep than at any other time.

#### SUMMARIZED RESULTS OF INDIVIDUAL EXPERIMENTS.

Table 23 summarizes the results of metabolism experiments Nos. 5, 6, 8, 9, 11, 13, 14, 21, 23-26, 28, 29, 31, 32 and 34.

TABLE 23.—PART I.

*Summary of income and outgo of nitrogen and carbon in 17 experiments, covering 57 days.*

Serial Number.	SUBJECT AND KIND OF EXPERIMENT.	Duration.—Days.	NITROGEN.				CARBON.				
			In food.	In feces.	In urine.	Gain (+) or loss (-).	In food.	In feces.	In urine.	In respiratory products.	Gain (+) or loss (-).
	<i>Rest Experiments.</i>		Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.
5	Subject E. O., - -	4	19.1	1.7	18.1	— .7	248.9	13.8	11.6	231.7	—8.2
8	Subject E. O., - -	4	20.8	1.3	19.5	0.0	270.7	10.6	13.9	224.5	+21.7
9	Subject E. O., - -	4	19.1	1.3	18.4	— .6	261.6	13.4	12.6	223.6	+12.0
13	Subject E. O., - -	3	18.7	1.1	19.5	—1.9	245.8	11.1	15.1	205.2	+14.4
14	Subject E. O., - -	4	15.1	.9	16.2	—2.0	239.0	7.4	12.2	207.3	+12.1
23	Subject E. O., - -	3	19.8	1.1	19.0	— .3	244.9	10.2	12.2	216.4	+6.1
24	Subject E. O., - -	3	19.8	1.3	18.2	+ .3	299.7	10.5	11.8	230.9	+46.5
	Av. 7 expts. E. O., -	25	18.9	1.2	18.4	— .7	258.7	11.0	12.8	219.9	+15.0
21	Subject A. W. S., -	3	15.5	1.0	15.4	— .9	215.2	9.0	10.8	217.4	—22.0
25	Subject J. F. S., - -	3	17.7	1.0	16.4	+ .3	270.9	9.7	12.9	216.6	+31.7
26	Subject J. F. S., - -	3	15.9	1.1	15.4	— .6	233.2	9.4	11.0	196.1	+16.7
28	Subject J. F. S., - -	3	15.8	1.2	15.3	— .7	245.8	10.0	10.9	210.7	+14.2
	Av. 3 expts. J. F. S., -	9	16.5	1.1	15.7	— .3	250.0	9.7	11.6	207.8	+20.9
	Av. 11 rest expts., -	37	17.9	1.2	17.4	— .6	252.4	10.5	12.3	216.4	+13.2
	<i>Work Experiments.</i>										
6	Subject E. O., - -	4	19.1	1.5	16.5	+1.1	336.7	12.4	12.5	345.2	—33.4
11	Subject E. O., - -	4	19.8	2.2	18.1	— .5	373.5	20.2	12.7	372.6	—32.0
	Av. 2 expts. E. O., -	8	19.5	1.9	17.3	+ .3	355.1	16.3	12.6	358.9	—32.7
29	Subject J. F. S., - -	3	16.0	.8	16.0	— .8	333.6	8.3	11.2	334.9	—20.8
31	Subject J. F. S., - -	3	16.1	.8	15.6	— .3	321.5	8.1	10.9	315.8	—13.3
32	Subject J. F. S., - -	3	16.1	1.2	15.7	— .8	320.0	12.6	11.0	325.6	—29.2
34	Subject J. F. S., - -	3	16.0	1.2	16.7	—1.0	335.7	11.6	11.6	345.4	—32.9
	Av. 4 expts. J. F. S., -	12	16.1	1.0	16.0	—1.0	327.7	10.2	11.2	330.4	—24.1
	Av. 6 work expts., -	20	17.2	1.3	16.4	— .5	336.8	12.2	11.7	339.9	—26.9
	Av. all (17) expts., -	57	17.7	1.2	18.3	— .6	282.2	11.1	12.1	283.1	—1.0

showing the income and outgo of nitrogen, carbon and energy, and the gain or loss of body material in each experiment. The results are here grouped according to the character of the experiment, whether rest or work, and sub-grouped according to the person serving as subject. In each case the average given is computed for the total number of days of the experiments

TABLE 23.—PART II.

*Summary of gain or loss of body material and of income and outgo of energy in 17 experiments covering 45 days.*

Serial Number.	SUBJECT AND KIND OF EXPERIMENT.	BODY MATERIAL.		ENERGY.								
		Protein gained (+) or lost (-).	Fat gained (+) or lost (-).	Of food.	Of feces.	Of urine.	Of body protein gained (+) or lost (-).	Of body fat gained (+) or lost (-).	Of material actually oxidized. Net income.	Measured as heat. Net outgo.	Difference between net income and net outgo.	
	<i>Rest Experiments.</i>	Grams.	Grams.	Cal.	Cal	Cal	Cal.	Cal.	Cal.	Cal.	Cal.	%
5	Subject E. O., - -	-4.2	-7.8	2655	143	128	-24	-73	2482	2379	-103	-4.1
8	Subject E. O., - -	0.0	+28.3	2897	117	153	00	+266	2361	2287	-75	-3.2
9	Subject E. O., - -	-3.6	+18.2	2717	142	149	-21	+171	2277	2309	+32	+1.4
13	Subject E. O., - -	-11.7	+26.9	2596	125	173	-67	+253	2112	2181	+69	+3.2
14	Subject E. O., - -	-12.4	+24.5	2513	82	142	-71	+229	2131	2103	-28	-1.3
23	Subject E. O., - -	-1.6	+9.6	2546	114	141	-9	+84	2216	2176	-40	-1.8
24	Subject E. O., - -	+1.7	+59.7	3061	116	136	+10	+561	2238	2272	+34	+1.5
	Av. 7 expts. E. O.,	-4.5	+22.7	2712	120	146	-26	+213	2260	2252	-8	-0.4
21	Subject A. W. S., -	-5.6	-24.9	2264	100	126	-32	-234	2304	2279	-25	-1.1
25	Subject J. F. S., -	+1.9	+40.4	2896	111	147	+11	+385	2242	2244	+2	+0.1
26	Subject J. F. S., -	-3.5	+24.4	2490	106	128	-20	+233	2043	2085	+42	+2.0
28	Subject J. F. S., -	-4.5	+21.8	2489	112	128	-26	+208	2067	2079	+12	+0.6
	Av. 3 expts. J. F. S.,	-2.0	+28.9	2625	110	134	-12	+275	2117	2136	+19	+0.9
	Av. 11 rest expts.,	-4.0	+20.0	2648	115	141	-23	+189	2225	2223	-2	-0.1
	<i>Work Experiments.</i>											
6	Subject E. O., - -	-6.9	+48.4	3678	139	125	+40	-455	3829	3726	-103	-2.7
11	Subject E. O., - -	-3.0	-39.7	3862	219	133	-17	-374	3901	3932	+31	+0.8
	Av. 2 expts. E. O.,	+2.0	-44.1	3770	179	129	+12	-415	3865	3829	-36	-0.9
29	Subject J. F. S., -	-5.0	-23.8	3487	93	134	-28	-227	3515	3589	+74	+2.1
31	Subject J. F. S., -	-2.3	-15.9	3495	91	129	-13	-151	3439	3420	-19	-0.6
32	Subject J. F. S., -	-5.0	-34.9	3487	142	119	-14	-350	3590	3565	-25	-0.7
34	Subject J. F. S., -	-11.9	-35.0	3493	126	126	-54	-350	3645	3587	-58	-1.6
	Av. 4 expts. J. F. S.,	-6.1	-27.4	3491	113	127	-27	-270	3547	3540	-7	-0.2
	Av. 6 work expts., -	-3.4	-33.0	3584	135	128	-14	-318	3653	3637	-16	-0.4
	Av. all (17) expts.,	-3.8	+1.3	2978	122	136	-19	+10	2729	2722	-7	-0.3

included in a given group. The results here summarized are used on the following pages in the discussion of the problems mentioned on page 102.

NOTE.—During the interval between the first and the last of these experiments, 13 experiments were carried on under the auspices of the Committee of Fifty for the Investigation of the Drink Problem, in connection with an independent investigation concerning the effect of alcohol in the diet. For convenience in keeping the laboratory records all experiments were numbered consecutively. These experiments in which alcohol formed a part of the diet comprised Nos. 7, 10, 12, 15-20, 22, 27, 30 and 33. The details of the first two were published in Bul. 69 of the Office of Experiment Stations of the U. S. Department of Agriculture; those of the remaining eleven will soon be published elsewhere.

#### FOOD MATERIALS SUPPLIED AND CONSUMED, AND THE DIFFERENCE IN DEMAND BY MEN AT REST AND AT WORK.

One of the objects of these experiments is to accumulate information regarding the demands of the body for food with different persons and under different conditions of rest and work. Data bearing upon this question are found in all of the metabolism experiments. In each case the ration was determined, as far as practicable, by the diet to which the subject had been accustomed under similar conditions. The details of the experiments\* show the total amounts and composition of the food, drink, and excretory products, from which are determined the actual income and outgo of material in the body and the gain or loss of protein and fat by the body, as set forth in Table 24. In this table the results of experiments Nos. 1-4 are included in addition to those summarized in Table 23.

By "available food" is understood the total food less the feces; in other words, the sum of the nutrients which are available to the body for the building of tissue and yielding energy. No correction is introduced for metabolic products in the feces, since these were derived originally from the food (or body tissue), and are a necessary accompaniment of undigested material. The available energy of the food is the total heat of combustion of the food minus the heat of combustion of the unoxidized materials of feces and urine. No further correction for the labor of chewing and digesting is included.

It is assumed that the quantity of carbohydrates in the body is the same at the beginning as at the end of the experiment. The gains and losses of protein and fat are computed from the

\* Published in the bulletins of the Office of Experiment Stations above referred to.



TABLE 24.

*Income and outgo of material in body, and gains and losses of protein and fat with different subjects and diets.—Amounts per day.*

SUBJECT, DURATION, AND CHARACTER OF EXPERIMENT.	Nitrogen.	Carbon.	Energy.	Protein.	Fat.
	Grams.	Grams.	Cal.	Grms.	Grms.
<i>Rest Experiments.</i>					
E. O. 9 experiments, 29 days, average:					
In available food, - - -	17.9	236.8	2495	112	—
In material oxidized, - - -	18.4	219.6	2282	115	—
Gain (+) or loss (—) in body, -	— .5	+17.2	—	—3	+25
O. F. T. 1 experiment, 5 days, average:					
In available food, - - -	14.4	216.5	2442	90	—
In material oxidized, - - -	13.7	219.9	2505	86	—
Gain (+) or loss (—) in body, -	+ .7	—3.4	—	+4	—7
A. W. S. 3 experiments, 9 days, average:					
In available food, - - -	14.7	214.3	2344	92	—
In material oxidized, - - -	13.7	229.1	2293	86	—
Gain (+) or loss (—) in body, -	+1.0	—14.8	—	+6	—24
J. F. S. 3 experiments, 9 days, average:					
In available food, - - -	15.4	228.7	2381	96	—
In material oxidized, - - -	15.7	207.8	2117	98	—
Gain (+) or loss (—) in body, -	— .3	+20.9	—	—2	+29
E. O., O. F. T., A. W. S., J. F. S. 16 experiments, 52 days, average:					
In available food, - - -	16.6	229.6	2444	104	—
In material oxidized, - - -	16.7	219.3	2277	105	—
Gain (+) or loss (—) in body, -	— .1	+10.3	—	—1	+14
<i>Work Experiments.</i>					
E. O. 2 experiments, 8 days, average:					
In available food, - - -	17.6	326.2	3462	110	—
In material oxidized, - - -	17.3	358.9	3865	108	—
Gain (+) or loss (—) in body, -	+ .3	—32.7	—	+2	—43
A. W. S. 1 experiment, 3 days, average:					
In available food, - - -	14.8	223.6	2505	92	—
In material oxidized, - - -	14.1	371.5	4325	88	—
Gain (+) or loss (—) in body, -	+ .7	—147.9	—	+4	—196
J. F. S. 4 experiments, 12 days, average:					
In available food, - - -	15.0	306.4	3251	94	—
In material oxidized, - - -	16.0	330.4	3547	100	—
Gain (+) or loss (—) in body, -	—1.0	—24.0	—	—6	—27
E. O., A. W. S., J. F. S. 7 experiments, 23 days, average:					
In available food, - - -	15.9	302.5	3227	99	—
In material oxidized, - - -	16.2	345.7	3759	101	—
Gain (+) or loss (—) in body, -	— .3	—43.2	—	—2	—55



gains and losses of the nitrogen and carbon.\* Accordingly, the figures show the average daily amounts of available protein and energy supplied by the food and the amounts actually used by the body when the subject had a minimum amount of exercise and when he was engaged in decidedly active muscular work.

The materials actually oxidized in the body are the available nutrients of the food minus the protein or fat gained or plus the protein or fat lost by the body. The data in the table show very clearly the demands of the body under the different conditions, and the increase in the demand which accompanied the performance of muscular work. In the rest experiments, the amounts of nitrogen in the available food and in the materials actually oxidized were larger with E. O. than with the other subjects. The amounts of carbon and energy in the available food were also larger with E. O., but there was comparatively little difference in the amounts actually metabolized. In the work experiments the amounts of nitrogen in the available food and in the material oxidized were not greatly different, for any of the subjects, from those in the rest experiments. The amounts of carbon and energy, however, were somewhat larger, the greatest increase in the amounts metabolized being in the case of A. W. S.

These experiments simply show the quantities of material and energy metabolized by a small number of men under specific conditions of work and rest. Their bearing upon the general subject of dietary standards can be more advantageously discussed when it is possible to take into account not only these and other experiments with men in the respiration calorimeter, but also a large number of experimental inquiries and observations of dietary usage of people of different classes and occupations in different countries.

There is no doubt that in many cases the body can be maintained in nitrogen and carbon equilibrium with much smaller quantities of nitrogen and energy than those actually used by any of the men in these experiments. It is equally certain that in other cases the requirements are much larger. The tentative standards for daily diet which have been proposed by

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\*By the method previously described, U. S. Dept. Agr., Office of Experiment Stations, Bul. 69, pp. 44, 45.

a number of investigators have served a useful purpose, but they will doubtless have to be modified as the fundamental data become more exact and numerous.

One principle which thus far has not received adequate recognition in dietary standards may perhaps be expressed by saying that the standards must vary, not only with the conditions of activity and environment, but also with the nutritive plane at which the body is to be maintained. A man may live and work and maintain bodily equilibrium on either a higher or lower nitrogen level or energy level. One essential question is: What level is most advantageous? The answer to this must be sought, not simply in metabolism experiments and dietary studies, but also in broader observations regarding bodily and mental efficiency, and general health, strength, and welfare.

#### ELIMINATION OF WATER.

The water taken into the body in the food and drink and formed by the oxidation of hydrogen is excreted by the kidneys, lungs, and skin. The amount eliminated by the kidneys varies with the amounts taken in the food and drink and eliminated in the respiration and perspiration, and is, in consequence, very irregular. The amount of water given off by the lungs and skin appears to depend largely upon the muscular activity of the subject and the temperature of the surrounding air, and to be less affected by the income in food and drink.

*Income and outgo of water per day.*—Table 25 recapitulates the figures for the average amounts of water taken in the food and drink and eliminated in the various excretions in the seventeen experiments previously enumerated. In all these experiments the days were divided into six-hour periods.

It is to be remembered that there was considerable milk in the daily diet and this is reckoned as food rather than drink. How the amounts of water in food and drink in these experiments would compare with those in the average diet in general it is impossible to say for lack of sufficient data. The average daily amount of water in food and drink together in the rest experiments was for E. O. 2,538 grams, for A. W. S. 2,275, and for J. F. S. 1,888 grams. In the work experiments with E. O. it was 2,771 grams, and with J. F. S. 2,225 grams.

TABLE 25.  
*Daily income and outgo of water.*

SUBJECT AND KIND OF EXPERIMENT.	Days covered by experiments.	INCOME.			OUTGO.			
		In food.	In drink.	Total.	In feces.	In urine.	In respiration and perspiration.	Total.
<i>Rest Experiments.</i>		Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.
E. O., 7 experiments:								
Minimum, - -		653	1290	2153	41	1037	697	2015
Maximum, - -		1270	1872	3047	98	3120	1143	4306
Average, - -	25	1058	1480	2538	63	1935	948	2946
A. W. S., 1 experiment:								
Minimum, - -		890	1384	2274	46	1628	821	2496
Maximum, - -		890	1385	2275	46	1609	808	2853
Average, - -	3	890	1385	2275	46	1743	859	2648
J. F. S., 3 experiments:								
Minimum, - -		1040	800	1840	19	913	791	1811
Maximum, - -		1078	900	1978	57	1489	879	2345
Average, - -	9	1055	833	1888	43	1219	830	2091
Avg. 11 expts.,	37	1044	1315	2359	57	1745	912	2714
<i>Work Experiments.</i>								
E. O., 2 experiments:								
Minimum, - -		951	1200	2151	91	815	1762	2911
Maximum, - -		1384	2100	3079	100	1275	2609	3981
Average, - -	8	1168	1603	2771	96	1011	2275	3382
J. F. S., 4 experiments:								
Minimum, - -		916	1250	2166	36	641	1197	2201
Maximum, - -		1036	1250	2286	72	1433	2004	3215
Average, - -	12	975	1250	2225	52	905	1670	2627
Avg. 6 expts., -	20	1052	1391	2443	70	947	1912	2929

The amount of urine excreted per day in the rest experiments averaged with E. O. 2,003 grams, containing 1,935 grams of water; with A. W. S. 1,798 grams, containing 1,743 grams of water, and with J. F. S. 1,266 grams, containing 1,219 grams of water. The average for the thirty-seven days of the rest experiments with the three subjects was 1,807 grams of urine, containing 1,745 grams of water. In the work experiments the amount of urine excreted averaged with E. O. 1,081 grams, containing 1,011 grams of water, and with J. F. S. 961 grams, containing 905 grams of water. The average for the twenty days of work experiments with both subjects was 1,009 grams of urine containing 947 grams of water.

The variations in the amounts excreted from day to day in experiments of the same kind with the same man were very wide. Thus, in the rest experiments with E. O. the urine fell on one day to 1,091 grams with 1,037 grams of water, while on another day it rose to 3,208 grams with 3,120 grams of water. It is to be observed that these experiments were made at different times during a period of two years and covered in all twenty-five days. In the rest experiments with A. W. S., on the other hand, there is but one experiment covering three days. Although the quantities of water in the food and drink were almost exactly the same from day to day, the quantities of urine and water in the urine were irregular, the range being from 1,681 grams of urine containing 1,628 grams of water to 1,965 grams of urine containing 1,909 grams of water. In the rest experiments with J. F. S. the quantities ranged from 975 grams of urine containing 913 grams of water to 1,551 grams of urine containing 1,489 grams of water. These extremes occurred respectively on the first and third days of the first experiment with this subject.

In the work experiments with E. O., made at intervals of over a year, the water of food and drink ranged from 2,151 to 3,079 grams per day. There were corresponding variations in the amount of urine and of water in the urine, though the range was not wide, the minimum amount of urine being 879 grams containing 815 grams of water, and the maximum 1,350 grams containing 1,275 grams of water. In the work experiments with J. F. S., which were made at short intervals during the same year, the water of food and drink ranged from 2,166 to 2,286 grams, and the variation in the amount of urine per day was from 695 grams of urine containing 641 grams of water, to 1,488 grams of urine containing 1,433 grams of water.

In comparing the averages of the rest and work experiments with both subjects E. O. and J. F. S., it will be observed that while the quantity of water in the food and drink was considerably larger in the work than in the rest experiments, the amounts of urine and water in the urine were larger in the latter than in the former. The differences, however, varied with the two subjects. Thus with E. O. the total income of water was over 10 per cent. larger in the work than in the rest experiments, but the outgo in the urine was but a little



over half as large in the former as in the latter. With J. F. S. the total income in the work experiments was nearly 20 per cent. larger than in the rest experiments, but the outgo in the urine was only three-fourths as large in the former as in the latter. With both subjects, the amount of solids in the urine was slightly larger in the work than in the rest experiments.

*Elimination of water by respiration and perspiration.*—The differences in the elimination of water in the urine in the rest experiments as compared with the work experiments finds a ready explanation in the figures for water in the respiration and perspiration. The amounts of water thus eliminated by E. O. averaged 2,275 grams in the work experiments as compared with 948 grams in the rest experiments; and by J. F. S. 1,670 grams in the work experiments as compared with 830 grams in the rest experiments. In other words, it is evident that the water eliminated by the kidneys depends upon the ratio of water in the food and drink to water of respiration and perspiration. The kidneys rid the body of the water not thrown off by the lungs and skin.

It is commonly assumed that the expired air is saturated with moisture. Supposing this to be a fact, the quantity of water given off from the lungs would be proportional to the amount of expired air. In times of active muscular exercise the volume of this air is larger than in times of rest, and, consequently, the amount of water given off from the lungs would be larger. Furthermore, the perspiration from the skin increases greatly with the muscular activity. With E. O., the amount of water excreted per day from the lungs and skin in the work experiments was  $2\frac{1}{3}$  times as large as in the rest experiments. With J. F. S. it was twice as large in the work as in the rest experiments.

The balance of income and outgo of water is decided not only by the amounts in food and drink on the one hand, and by the amounts eliminated by the kidneys, lungs, and skin on the other, but also by two other factors. One of these is the amount of water formed within the body by the oxidation of hydrogen, the other is the change in the amount of water in the alimentary canal and in the tissues and fluids of the body. This topic, however, cannot be discussed further until additional data which are being accumulated are available.



One point, however, is so interesting that a word regarding it may be in place here. Comparisons of the figures for amounts of hydrogen oxidized, as given in the tabular details of the experiments, show that if all the water formed by the oxidation of the hydrogen of the food and body material were eliminated through the lungs and skin, and none through the kidneys, it would account for only about one-third of the water of respiration and perspiration in the rest experiments, and only about one-fourth of that in the work experiments. It is therefore evident that the increase of water of respiration and perspiration during periods of muscular activity is due not so much to an increased oxidation of hydrogen as to an increased excretion through the lungs and skin of water from some other source.

The amounts of water eliminated by the lungs and skin in the different periods of the day as compared with the day as a whole are shown in Table 26.

In the rest experiments with E. O. the total amount of water of respiration and perspiration ranged from 697 to 1,143, and averaged 948 grams per day. Comparing the twelve hours of the day with the twelve hours of the night, the amounts of water eliminated were practically the same, being, respectively, 49.5 and 50.5 per cent. of the whole. Comparing by periods, the largest elimination, 42.6 grams per hour, was in the first, and the smallest 37.3 grams per hour, in the last of the night periods, but the differences in the different periods were not large. The amounts with A. W. S. were somewhat smaller, the average daily elimination being 859 grams. Here again it was equally divided between the day and the night, and the amounts in the six-hour periods differed but little, although the amount in the first night period was slightly larger than that in the second night period, the latter being little smaller than in either of the day periods, as was the case with E. O. The average daily elimination with J. F. S., 830 grams, was still less than with A. W. S. In this case the elimination was somewhat larger during the day than during the night periods, being 52 per cent. of the whole for the former as compared with 48 per cent. for the latter. The average for both the day periods was the same, 36.0 grams. As was the case with the two other subjects, the average for the first night period was

larger than that for the second. Taking the rest experiments with the three subjects together, the daily average for thirty-seven days was 912 grams, or 38.0 grams per hour. The amounts per hour in the four periods were respectively 37.2, 39.0, 40.4 and 35.4 grams, or 24.5, 25.6, 26.6 and 23.3 per cent. of the total for the day.

TABLE 26.

*Water eliminated by lungs and skin.—Amounts per day, and rates and proportions for different periods.*

SUBJECT AND KIND OF EXPERIMENT.	Days covered by expts. Total amount in 24 hours.	RATE PER HOUR.						PROPORTION OF TOTAL FOR 24 HOURS.			
		7 A. M. to 1 P. M.		1 P. M. to 7 P. M.		7 P. M. to 1 A. M.		1 A. M. to 7 A. M.		For 24 hours.	
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.					
		7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.							

In the work experiments, in which the subjects E. O. and J. F. S. were engaged in active muscular work eight hours each day between 7. A. M. and 7 P. M., the average daily outgo of water through lungs and skin was increased to 1,912 grams per

day. With E. O. this increase is noticeable in all four periods, but is especially marked in the first day period, the average in that period being three times as great in the work as in the rest experiment. In the majority of cases the amount gradually fell off during the subsequent periods; but even during the last night period the average was nearly  $1\frac{3}{4}$  times as large for the work as for the rest experiments. Of the total daily amount 60.3 per cent. was given off during the two day periods, and 39.7 per cent. during the two night periods. With J. F. S. there was an increase in elimination during the day periods only, being most noticeable in the second, in which it was three times as large in the work as in the rest experiments. The elimination during the night periods was practically the same in the work as in the rest experiments. Of the total daily amount eliminated by this subject in the work experiments, 75.5 per cent. was given off during the two day periods, and 24.5 per cent. during the two night periods. In the average of the experiments with the two subjects the amounts for the four periods were respectively 107.2, 110.3, 55.1 and 46.0 grams per hour, or 33.7, 34.6, 17.3 and 14.4 per cent. of the total.

The parallelism between muscular work and increased water elimination by the lungs and skin is not close, nor does the increase coincide at all exactly with the period of work. The "lag" in elimination of water, i. e., the length of time between its ingestion in food and drink or its formation by the oxidation of hydrogen on the one hand and its elimination by various channels on the other is decided by factors too complex for full discussion here, and is reserved for discussion in the light of later experiments.

#### ELIMINATION OF CARBON DIOXID.

The carbon dioxid given off from the body is derived wholly from the oxidation of the carbon of the food and body material, and hence serves as a measure of the amount of that oxidation. The quantity given off in the urine and feces is very small indeed. It is here neglected, and that given off by the lungs and skin is taken as representing the total elimination. The quantity eliminated in a given period depends upon a variety of conditions, among which are (1) the character of the diet and

the time which has elapsed since the last meal was taken, (2) the muscular activity of the subject, whether at rest or at work, (3) the external temperature, (4) the age and body weight, and (5) individual peculiarities of the subject. The accuracy with which the carbon dioxid eliminated for a given period measures the production for that period depends upon the so-called "lag" in the elimination, a topic to be discussed in another place.

In the experiments here considered there are considerable fluctuations in the output. Of the factors which cause these fluctuations the most important is the muscular activity. The differences in the food were mainly those called for by the differences in the muscular exercise. The external temperature, i. e., that of the air in the chamber, was kept as near to 20°C. as convenient. The subjects were young, healthy, active men, of similar age, height, and weight, but differing slightly in the amounts of food to which they were accustomed, so that there was nothing to imply differences in personal characteristics so great as to effect materially the oxidation of carbon.

The figures for the daily elimination of carbon dioxid are summarized in Table 27, which shows the average amount per hour during each period and for the whole day, and the percentage which the output for each period makes of the average amount for twenty-four hours.

The elimination of carbon dioxid under conditions of rest averaged 796 grams per day, or 33.2 grams per hour, in the twenty-five experimental days of the seven experiments with E. O.; 797 grams per day, or 33.2 grams per hour, in the three experimental days of one experiment with A. W. S.; and 762 grams per day, or 31.8 grams per hour, in the nine experimental days of three experiments with J. F. S. The range was from 739 to 879 grams per day with E. O., from 787 to 816 with A. W. S., and from 715 to 801 with J. F. S. It will be remembered, however, that the experiments with E. O. were made at different times during two years, while with A. W. S. there was but a single experiment. The experiments with J. F. S. were made at short intervals during one year. In eight experimental days of the two experiments in which the subject E. O. was engaged in active muscular work for eight hours each day the output averaged 1,316 grams per day, or 54.8



grams per hour; while in twelve experimental days in which the subject J. F. S. was similarly engaged it was 1,212 grams per day or 50.5 grams per hour.

TABLE 27.

*Carbon dioxid eliminated by lungs and skin.—Amounts per day, and rates and proportions in different periods.*

SUBJECT AND KIND OF EXPERIMENT.	Days covered by expts.	Total amount in 24 hours.	RATE PER HOUR.					PROPORTION OF TOTAL IN 24 HOURS.			
			7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	For 24 hours.	7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.
			Gm.	Gm.	Gm.	Gm.		Gm.	%	%	%
<i>Rest Experiments.</i>											
E. O., 7 experiments:											
Minimum, - -		739	35.1	33.2	31.2	20.4	30.8				
Maximum, - -		879	43.2	42.8	42.2	25.6	36.6				
Average, - -	25	808	38.3	37.8	36.1	22.4	33.7	28.5	28.1	26.8	16.6
A. W. S., 1 expt.:											
Minimum, - -		787	38.1	35.9	30.9	21.8	32.8				
Maximum, - -		816	41.5	38.2	33.7	24.3	34.0				
Average, - -	3	797	39.8	37.1	32.8	23.2	33.2	29.9	27.9	24.7	17.5
J. F. S., 3 expts.:											
Minimum, - -		715	33.4	33.2	28.1	21.2	29.8				
Maximum, - -		801	39.7	40.1	36.3	23.3	33.4				
Average, - -	9	762	37.0	36.1	31.6	22.3	31.8	29.1	28.4	24.9	17.6
Av. of 11 expts.,	37	796	38.1	37.3	34.8	22.5	33.2	28.7	28.1	26.2	17.0
<i>Work Experiments.</i>											
E. O., 2 expts.:											
Minimum, - -		1195	69.4	65.0	33.9	19.9	49.8				
Maximum, - -		1510	90.2	98.2	42.2	26.2	62.9				
Average, - -	8	1316	78.4	79.5	38.4	23.1	54.8	35.7	36.3	17.5	10.5
J. F. S., 4 expts.:											
Minimum, - -		1080	63.4	61.9	27.8	21.0	45.0				
Maximum, - -		1292	81.0	79.8	36.2	24.1	53.9				
Average, - -	12	1212	73.6	74.7	31.3	22.3	50.5	36.5	37.0	15.5	11.0
Av. of 6 expts.,	20	1253	75.5	76.6	34.1	22.6	52.2	36.2	36.7	16.3	10.8

During the rest experiments, in which the subjects had as little muscular activity as possible, there was but little difference in the elimination of carbon dioxid during the two day and first night periods. In the seven experiments with E. O. the average rate per hour during these three periods was 38.3, 37.8, and 36.1 grams, respectively. In the experiment with



A. W. S. there was a slightly larger amount of carbon dioxid eliminated in the first two than in the third period, the rates being 39.8, 37.1, and 32.8 grams, respectively. In the four experiments with J. F. S. the elimination during the first three periods averaged 37.0, 36.1, and 31.6 grams per hour, respectively. During the second night period, when the subject was generally asleep for nearly the whole time, the output fell off with E. O. to 22.4, with A. W. S. to 23.2 and with J. F. S. to 22.3 grams per hour. Not only are the averages with the three men in close accord, but the range of variation in the different days and experiments is decidedly narrow for all. In the average of the eleven experiments the proportion given off in each of the four periods of the day is 28.7, 28.1, 26.2, and 17.0 per cent., respectively.

The elimination of carbon dioxid in the two day periods of the work experiments was more than twice as large as in the two day periods of the rest experiments. With E. O. the average amounts given off were 78.4 grams in the first and 79.5 in the second day period when at work as compared with 38.3 and 37.8 grams, respectively, when at rest. With J. F. S. the amounts averaged 73.6 and 74.7 grams in the day periods of the work experiments as compared with 37.0 and 36.1 grams in the corresponding periods of the rest experiments. The elimination in the two night periods averaged with E. O. 38.4 and 23.1 grams in the work experiments as compared with 36.1 and 22.4 grams in the rest experiments, the differences being small; with J. F. S. the amounts were practically identical, being 31.3 and 22.3 grams in the work experiments as compared with 31.6 and 22.3 grams in the rest experiments.

The uniformity in the amounts of carbon dioxid given off during the second night period in all the experiments is very noticeable. Such data may perhaps be taken as an approximate measure of the metabolism of carbon in the body of an active healthy man when at its lowest ordinary ebb.

#### ELIMINATION OF ENERGY.

*Measurements of energy.*—The kinetic energy given off by the body is measured in these experiments as the sum of three quantities: (1) The heat taken up by the water current in its passage through the chamber; (2) the latent heat of the

water vapor given off by the body—i. e., of the water vaporized by its heat and carried out in the air current, due corrections being made for water condensed upon the absorbers; (3) the heat equivalent of the muscular work done.

In the measurements of energy of income and outgo of the body the temperature of the interior of the chamber, generally about twenty degrees, is taken as the basis for computations of the heat removed or given off by food, drink, and excretory products in the chamber.\*

(1) The heat carried away by the water current includes (*a*) the heat given off from the skin by radiation and conduction; (*b*) that brought out of the body in the feces and urine and given off in the cooling of these excretory products to the temperature of the chamber; (*c*) that brought out of the body in the air, carbon dioxide, and water excreted by the lungs and skin and given off in their cooling to the same temperature; (*d*) the latent heat of vaporization of so much of the water of *c* as is permanently condensed on the absorbers (mainly collected as drip water), and (*e*) the heat produced by the transformation of the external muscular work. The heat of *a*, *b*, *c*, and *e* finds its way by radiation and conduction to the surface of the copper absorbers and passes with that of *d* into the water current, by which it is carried out of the chamber.

(2) Although the air current enters and leaves the chamber at the same temperature, it carries out more heat than it brings in. The extra heat carried out is the latent heat of the water vapor added to the air of the chamber by the subject.† The amount of this heat is learned from the amount of water vapor and its latent heat of vaporization at the given temperature.

(3) The external muscular work is measured and the heat equivalent calculated. Before leaving the chamber it is transformed into heat, which is carried away by the water current, as above stated.

*Energy given off in different ways as heat and as external muscular work.*—The average amounts of energy given off by the body per day in the different ways are shown in Table 28.

\* U. S. Dept. Agr., Office of Experiment Stations, Bul. 69, p. 20.

† The differences in specific heat of the air due to loss of oxygen and gain of carbon dioxide are here assumed to be negligible.

TABLE 28.

*Energy given off by the body in different ways.—Amounts per day.*

SUBJECT AND KIND OF EXPERIMENT.	Days covered by experiments.	HEAT ELIMINATED.			Heat equivalent of muscular work.	Total.
		By radiation and conduction.	In urine and feces.	In water vaporized from lungs and skin.		
<i>Rest Experiments.</i>						
E. O., 7 experiments:		Cal.	Cal.	Cal.	Cal.	Cal.
Minimum, - - - - -		1479	19	412	—	2062
Maximum, - - - - -		1835	56	673	—	2452
Average, - - - - -	25	1673	35	551	—	2259
A. W. S., 1 experiment:						
Minimum, - - - - -		1710	30	486	—	2226
Maximum, - - - - -		1782	34	531	—	2348
Average, - - - - -	3	1739	32	509	—	2279
J. F. S., 3 experiments:						
Minimum, - - - - -		1564	17	468	—	2065
Maximum, - - - - -		1759	27	520	—	2297
Average, - - - - -	9	1622	23	491	—	2136
Average of 11 experiments, - -	37	1666	32	533	—	2231
<i>Work Experiments.</i>						
E. O., 2 experiments:						
Minimum, - - - - -		2045	17	1041	193	3473
Maximum, - - - - -		2521	25	1560	270	4287
Average, - - - - -	8	2249	20	1332	228	3829
J. F. S., 4 experiments:						
Minimum, - - - - -		2185	13	709	127	3253
Maximum, - - - - -		2400	27	1240	277	3890
Average, - - - - -	12	2296	18	988	238	3540
Average of 6 experiments, - -	20	2277	19	1126	234	3656

The figures in the second column are obtained by subtracting the sum of the quantities of heat given off by the feces and urine in cooling and by the water in condensing on the absorbers and the heat equivalent of the external work ( $b + d + e$  above) from the total heat taken from the chamber by the water current. Accordingly they represent the sum of the quantities of heat given off by the skin directly and by the product of respiration and perspiration in cooling to the temperature of the room ( $a + c$  above). It is hoped that it will be possible later to make at least approximate estimates of the latter quantity and thus show the amount of heat given off by the skin alone.

The figures for the heat given from the urine and feces, as shown in the third column in Table 28, are calculated from the weights of these excreta, their fall in temperature and their specific heats. The weights are found by the balance. The fall in temperature is the difference between the temperature of the body and that of the interior of the chamber. This difference averages about seventeen degrees. The specific heats are arbitrarily assumed, that of feces being taken as 0.9 and of urine 1.0.

The figures in the fourth column represent the latent heat of vaporization of the water given off by the lungs and skin. For the rest experiments this water is in general that carried out of the chamber in the air current in excess of that brought into the chamber by the same current. In a few rest experiments, however, and in all the work experiments more or less water is condensed on the absorbers and is not carried out by the air current. The figures in the third column include the heat given off in the condensation of this water vapor upon the absorbers along with the latent heat of vaporization of the water in the air current. The reason why little or no water was condensed on the surfaces of the absorbers in the rest experiments is that the temperature of the incoming water current was as a rule above the dew-point of the air inside the chamber.

The fifth column shows the heat equivalent of the external muscular work done in the work experiments. It is measured by the bicycle dynamo apparatus by which the mechanical work is transformed into electrical energy and into heat.

According to the figures of Table 28, in the thirty-seven days of the eleven rest experiments the average amounts of heat given off per day from the skin (together with that in the expired air) was 1,666, in urine and feces 32, and in the water vaporized from the lungs and skin 533 calories, making the whole daily elimination 2,231 calories. With E. O. the range in total heat eliminated was from 2,062 to 2,452 and the average 2,259 calories. With A. W. S. the range was from 2,226 to 2,348 and the average 2,279 calories. With J. F. S. the range was from 2,065 to 2,297, and the average 2,136 calories. Taking into account the experiments with all the subjects the average amounts of heat given off in different ways may be expressed in percentages as follows:



TABLE 29.

*Percentages of total energy given off from the body in different ways.*

HEAT.	In rest experiments.	In work experiments.
	%	%
From skin by radiation and conduction (and in exhaled air), - - - - -	74.2	62.3
In urine and feces, - - - - -	1.4	.5
In water vaporized from lungs and skin, - -	24.4	30.8
Heat equivalent of external muscular work done,	—	6.4
Total, - - - - -	100.0	100.0

*Energy given off from the body in different periods of the day.*  
 —Table 30 summarizes the data for the outgo of energy during the different periods of the day in the seventeen experiments, covering fifty-seven experimental days. As in the two previous tables, the figures for heat eliminated include (1) the quantity given off from the body and measured by the calorimeter, (2) that given off in the water vaporized during the same periods, i. e., carried away from the body in water vapor, and (3) the heat equivalent of the external muscular work done. The temperature of the body and the amount of material it contains varies somewhat from time to time. It is assumed that at the hour when the experimental day begins and ends, 7. A. M., they will be very nearly the same from day to day. If they are the same at these times the total quantity of heat in the body at the beginning and end of each experimental day will be the same. The total quantity of energy given off from the body during the day will in this case be equivalent to the total amount liberated within the body, and will be closely parallel with the amounts of carbon and hydrogen oxidized. Taking each of these four periods of the day by itself the differences between the amounts of heat stored in the body at the beginning and end will probably be larger than is the case for the whole day. For individual periods, therefore, the parallelism between the amounts of carbon oxidized and heat given off will hardly be as close as for the whole day.



TABLE 30.

*Heat given off by body, including for the work experiments the heat equivalent of the external muscular work.—Amounts per day and rates and proportions for different periods.*

SUBJECT AND KIND OF EXPERIMENT.	Days covered by expts.	Total amount in 24 hours.	RATE PER HOUR.					PROPORTION OF TOTAL FOR 24 HOURS.			
			7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.	Average for 24 hours.	7 A. M. to 1 P. M.	1 P. M. to 7 P. M.	7 P. M. to 1 A. M.	1 A. M. to 7 A. M.
			Cal.	Cal.	Cal.	Cal.	Cal.	Cal.	%	%	%
<i>Rest Experiments.</i>											
E. O., 7 expts.:		Cal.	Cal.	Cal.	Cal.	Cal.	Cal.	%	%	%	%
Minimum, -		2062	94.5	90.4	83.9	62.8	85.9				
Maximum, -		2452	116.6	124.0	121.8	77.8	102.2				
Average, -	25	2259	103.3	103.8	100.7	68.7	94.1	27.4	27.6	26.7	18.3
<i>A. W. S., 1 expt.:</i>											
Minimum, -		2226	111.6	101.6	91.9	62.7	92.8				
Maximum, -		2348	119.8	106.9	94.3	70.4	97.8				
Average, -	3	2279	114.5	104.5	93.3	67.5	95.0	30.1	27.5	24.6	17.8
<i>J. F. S., 3 expts.:</i>											
Minimum, -		2065	104.8	93.5	80.0	58.1	86.0				
Maximum, -		2297	119.9	103.6	98.7	64.4	95.7				
Average, -	9	2136	109.0	98.7	88.2	60.2	89.0	30.6	27.7	24.8	16.9
Av. 11 expts.,	37	2230	105.7	102.5	97.0	66.5	92.9	28.4	27.6	26.1	17.9
<i>Work Experiments.</i>											
E. O., 2 expts.:											
Minimum, -		3473	195.3	192.8	108.0	68.8	144.7				
Maximum, -		4257	240.5	281.8	128.8	79.6	178.6				
Average, -	8	3829	212.2	231.5	120.5	74.0	160.0	33.3	36.3	18.9	11.6
<i>J. F. S., 4 expts.:</i>											
Minimum, -		3253	187.8	185.5	89.9	60.1	135.5				
Maximum, -		3890	239.9	241.3	111.0	70.0	162.1				
Average, -	12	3540	212.0	216.7	97.2	64.2	147.5	35.9	36.7	16.5	10.9
Av. 6 expts.,	20	3656	212.0	222.5	106.5	68.2	152.3	34.8	36.5	17.5	11.2

From the quantities of heat given off from the body in the different periods of the day, as summarized in Table 30, it will be noted that in the thirty-seven days of the eleven rest experiments with E. O., A. W. S., and J. F. S. the average amounts of heat given off per hour in the four successive six-hour periods from 7 A. M. to 7 A. M. were 103.3, 103.8, 100.7, and 68.7 calories, respectively, the average hourly rate for the whole

day being 94.1. The percentages of the whole amount for the day given off in the several periods are 27.4, 27.6, 26.7, and 18.3, respectively.

The average hourly rate for the twenty days of the six work experiments with E. O. and J. F. S. was 152.3 calories. The rates for the different periods beginning with 7 A. M. were 212.0, 222.5, 106.5, and 68.2 calories, respectively. The corresponding percentages are 34.8, 36.5, 17.5, and 11.2.

It thus appears that for the two day periods in which the subjects were engaged in active muscular exercise for eight hours the quantity of heat given off was more than twice as large as in the corresponding periods of the rest experiments. In the first night period the amount per hour in the work experiments was not greatly in excess of that in the rest experiments (106.5 calories as compared with 97.5). In the second night period the quantities were more nearly the same (68.2 calories in the work experiments and 66.5 in the rest experiments).

The uniformity in the amounts of heat given off during the second night period calls for special notice. In the rest experiments with E. O., covering twenty-five days, the range is from 62.8 to 77.8 and the average 68.7 calories per hour; in the experiment with A. W. S., covering three days, the range per hour is from 62.7 to 70.4 and the average 67.5 calories. In the twelve days of the work experiments with E. O. the amounts are a little larger than in the rest experiments with the same subject, ranging from 68.8 to 79.6 and averaging 74.0 calories per hour. That the elimination of heat during this period is larger in the work than in the rest experiments is perhaps explained by the fact that while the subject was decidedly tired at night, and supposed that he slept more soundly than in the rest experiments, he moved more, and to the observers outside the chamber appeared more restless. In the work experiments with J. F. S. also the amounts during this period are slightly larger than in the rest experiments, ranging from 60.1 to 70.0 and averaging 64.2 calories per hour. It is noticeable that in the second night period the rate with J. F. S. is smaller than that with E. O., the ratio of the former to the latter being about the same in both work and rest experiments.

From the results obtained in the second night periods in these experiments, it would seem that from 65 to 70 calories per hour might be not far from representing an average elimination of heat by a healthy, active man in the time of minimum bodily activity.

*Relation between elimination of heat and of carbon dioxide.*—

The rates of elimination of heat and of carbon dioxide in the different periods are nearly parallel, as will be seen by comparing the figures of Tables 30 and 27. Both these values in the two day periods of the work experiments are largely in excess of the similar values in the same periods of the rest experiments. The values for both these factors in the second night period of the same experiments, which was one of quiet sleep, were small and noticeably uniform.

INCOME AND OUTGO OF ENERGY.

Perhaps the most interesting results of these experiments, both because of their novelty and because of their bearing upon the metabolism and the conservation of energy in the living organism, are those which compare the amounts of potential energy in the materials actually oxidized in the body with the amounts of kinetic energy given off from the body either as heat alone in the rest experiments or as heat and external muscular work in the work experiments. In the rest experiments there was no considerable amount of external muscular work. The little that was done would naturally be converted into heat, as, for instance, in the impact of the foot upon the floor in stepping, or of the body upon the chair or bed in sitting or lying down. The heat thus imparted to the floor, chair, or bed would naturally find its way to the absorbers, and would be carried out with the heat given off as such by the body. Roughly speaking, we may say that all the potential energy made kinetic in the body by the oxidation of food and body material left the body as heat. This is shown by the agreement of the amount of heat given off from the body with the heat of oxidation of the material oxidized in the body. These data are summarized in Table 31.

TABLE 31.

*Comparison of income and outgo of energy in experiments covering 57 experimental days.—Amounts per day.*

SUBJECT AND KIND OF EXPERIMENT.	Number of experi- mental days.	Net income (potential energy of material oxidized in body).	Net outgo (kinetic energy given off from body).	Difference (in terms of net income).	
<i>Rest Experiments.</i>		Cal.	Cal.	Cal.	%
Experiments with E. O.:					
Experiment in which the net outgo falls farthest below the net income (No. 5); average for the whole experiment, -	4	2482	2379	-103	-4.1
Experiment in which the net outgo is far- thest above the net income (No. 14); average for the whole experiment, -	4	2131	2193	+62	+2.9
Average for 7 experiments, - - -	25	2268	2259	-9	-.4
Experiment with A. W. S.:					
Average for one experiment, - - -	3	2304	2279	-25	-1.1
Experiments with J. F. S.:					
Average for 3 experiments, - - -	9	2118	2136	+18	+.8
Experiments with E. O., A. W. S., and J. F. S.:					
Average for 11 experiments, - - -	37	2234	2230	-4	-.2
<i>Work Experiments.</i>					
Experiments with E. O.:					
Average for 2 experiments, - - -	8	3865	3829	-36	-.9
Experiments with J. F. S.:					
Average for 4 experiments, - - -	12	3547	3540	-7	-.2
Experiments with E. O. and J. F. S.:					
Average for 6 experiments, - - -	20	3674	3656	-18	-.5
<i>Rest and Work Experiments.</i>					
Average for 17 experiments, - - -	57	2740	2731	-9	-.3

The figures for income and outgo of energy require a word of explanation. A distinction is here made between the total\* income, which is represented by the potential energy of the food, and the net\* income, which is the energy of the material actually oxidized in the body. This energy of net income is represented by the potential energy of the available nutrients

\* The terms "total" and "net" here applied to income and outgo of material and energy are used for present convenience and may in future reports be replaced by more appropriate expressions.



of the food (i. e., energy of total food less that of the urine and feces) minus the potential energy of the material gained, or plus that of material lost by the body when the latter is not in nitrogen and carbon equilibrium. The total energy of outgo would be the kinetic energy given off from the body in heat and external muscular work, plus the potential energy of the unoxidized materials in the urine and the feces. The net energy of outgo consists of the heat given off and the external muscular work done. The balance of income and outgo is best shown by the net rather than the total quantities. These may be seen in Table 31. The averages for the groups of experiments are for the number of days covered by the whole group, i. e., they are not averages for individual experiments.

It is to be remembered that the figures for net income of energy represent the heats of combustion of the material actually oxidized. This material consists mainly of the available portions of the food of which the amounts and heats of combustion are found by direct determination. To the heat of combustion is added that of material lost, or from it is subtracted that of the material gained by the body. The amounts of material gained or lost are determined from the gain or loss of nitrogen and carbon, and their heats of combustion are calculated by the use of factors based upon direct determinations of the heats of combustion of similar substances. The figures for net outgo are the results of direct experimental measurement. In other words, the net income of energy is mainly and the net outgo entirely the result of direct determinations.

A common usage is followed in applying the term potential energy to the energy latent in the food and body material oxidized. Whether chemical energy would or would not be a more correct expression no attempt is here made to decide. Ordinary usage is also followed in expressing potential energy in terms of heat, i. e., as calories, thus employing a unit of kinetic energy for the measure. This discrepancy is unavoidable, since there is a lack both of means for measuring potential energy as such and of a unit for expressing such measurements. The use of heat of oxidation for the measure is especially appropriate here, since the energy is liberated mainly by oxidation and appears chiefly or entirely as heat.



*The conservation of energy in the body.*—If the law of the conservation of energy obtains in the living organism, the net income and the net outgo of energy should be the same. In such physiological experimenting, however, it would be hardly fair to expect the figures for the two to agree for each day of a given experiment, or for each experiment as a whole, even if the measurements with the respiration and bomb calorimeters are exact. There may be errors in the estimates of the amounts and heats of combustion of the materials actually oxidized. Variations due to irregularities of the physiological processes of the body are unavoidable and may materially affect the results. For instance, the calculations assume that the quantities of material in the alimentary canal and of carbohydrates in the body as a whole are the same at the end as at the beginning of each day or experiment; whereas they may differ considerably, and the differences would materially affect the results. But it might be hoped that if the methods are correct, these errors would tend to counterbalance one another in a series of experiments, and that, in the average of a sufficiently large number, the errors would thus be eliminated so that the income and outgo would be very nearly the same.

Exactly this is the case in the data here reported. The variations for individual days, and even those for the individual experiments, as shown in the detailed tables of the publications mentioned elsewhere\* are not inconsiderable; but in the average of all the experiments the agreement is very close. Thus in twenty-five days of the seven rest experiments with E. O., according to the figures for the individual days the net outgo varies from 165 calories below to 194 calories above the net income. Expressed in percentages of net income, the range here is from  $-6.5$  to  $+9.1$  per cent. Both these extremes occurred on the first days of the respective experiments. In general the results for the first day of an experiment are found to be less satisfactory than those for the succeeding days. Considering the experiments each as a whole and comparing the averages of the several experiments one with another, the range of variation is less. Here the net outgo varies from 103 calories below to 62 calories above the net outgo per day. Expressed in percentages of net income, the range is from  $-4.1$

\* See page 96.

to  $\pm 2.9$  per cent. But in the average for the seven experiments the figures for the net income and outgo are practically the same, being 2,268 and 2,259 calories, respectively. In the average of the three days of the rest experiment with A. W. S. there is a disparity of 1.1 per cent., and in the average of the nine days of the three rest experiments with J. F. S. the difference is 0.9 per cent. Taking the thirty-seven days of the eleven rest experiments together, the average income is 2,234 and the average outgo 2,230 calories; the difference is 0.2 per cent. In the average of the eight days of the two work experiments with E. O. the net income and outgo are 3,865 and 3,829 calories, respectively, the difference being 0.9 per cent., and in the average of the twelve days of the four work experiments with J. F. S. the net income and outgo are 3,547 and 3,540 calories, or a difference of 0.2 per cent. Taking into account the six work experiments with E. O. and J. F. S. the net income is 0.5 per cent. larger than the net outgo. The averages for the fifty-seven days of the seventeen experiments are: Income, 2,740; outgo, 2,731 calories. The difference, 0.3 per cent., is far within the limits of experimental error and physiological uncertainties.

In experiments of this sort, which represent only the work of a period during which experience with new apparatus and methods is being accumulated, individual discrepancies, such as those above recorded, seem no larger than might naturally be expected. The agreement of the average results is much closer than we hoped for; indeed, it can hardly be otherwise than accidental, and we regard it as by no means certain that future averages will show so exact a balance.

The metabolism of energy in the living organism can be more profitably discussed when data not yet published are available. Taking into consideration all the experiments thus far made with the respiration calorimeter in which the balance of energy has been determined, it may be said that the general result scarcely falls short of definite and final demonstration that the law of the conservation of energy applies in the living organism.

## A STUDY OF RATIONS FED TO MILCH COWS IN CONNECTICUT.

BY C. S. PHELPS.

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In the winter of 1892-3 the Station began a study of rations fed to milch cows on dairy farms in this state, which has been continued up to the present time. During the first year the tests were in the nature of preliminary studies for the purpose of ascertaining the ordinary methods of feeding in practice among our dairymen, and a comparatively large number of tests were made. Beginning with the winter of 1893-4 and continuing up to 1897 series of tests were made for the purpose of studying the relative economy of such rations as farmers were feeding their herds in their own practice, as compared with other rations, generally richer in protein, which were proposed by the Station. Each herd studied was selected after a personal inspection in order to ascertain its fitness for the proposed tests. A representative of the Station was present during the whole period of the tests and personally attended to the details of the experiments, such as the weighings of the feeds, taking samples for analysis, weighing and sampling of milk and determining the butter fat in the milk by the Babcock method. The chief points observed in the experiments were:

*Number of animals in the herd.*—Only such cows as were giving a fair quantity of milk at the time of the test were included in the study. Cows which were nearly dry, or were "off feed," or for any reason did not seem representative of the herd were excluded entirely from the group under observation.

*Breed, age and approximate weight of each cow.*—The breed and age were obtained as accurately as possible from the owner. Since it was not practicable to carry to the farm scales large enough to weigh the cows, the weights were estimated by either

the Station representative or the owner, and it is believed that the errors of judgment were not large. The weight was estimated to the nearest twenty-five pounds.

*Number of months since the last calf.*—In most cases the time since the cow dropped her last calf was known and was recorded.

*Number of months till due to calf.*—There was more or less uncertainty in regard to this point but in most cases it could be approximately ascertained.

*Daily milk yield during the tests.*—The milk of each cow at each milking was weighed to the nearest tenth of a pound by the Station representative.

*Percentages and amounts of butter fat in the milk.*—A sample of the milk of each cow, night and morning, was taken and from the combined sample a determination of the percentage of butter fat was made by the Babcock method. From the percentages of butter fat and the weight of milk the daily yields of butter fat were computed.

*Kinds and weights of foods used.*—During all the tests of the first year and the first tests on each herd of later years, the dairyman or farmer was requested to use as nearly as possible the same ration as he had been feeding immediately before the test began. The quantity of food for each animal was weighed by the Station representative just before feeding. If any considerable portion of the food was left uneaten by the cows it was weighed and due allowance was made in estimating the amounts eaten daily.

During the early part of the test samples of each feeding stuff used were taken and sent to the laboratory for analysis, in order to determine the actual amounts of the different nutrients in the daily ration. Estimates were made of the amounts of digestible nutrients in the ration fed each herd, and a new ration was suggested which should furnish a considerably larger proportion of digestible protein, and have a correspondingly narrower nutritive ratio. In some cases the analyses of the feeds used in the first tests could not be made in season to be of use as a basis for calculating the new ration, and in other cases only the nitrogen (and protein) was determined at the time. Under such circumstances average figures for composition were



taken from a compilation of analyses and were used in computing the nutrients in the ration fed, and the new ration was based upon these computations. In all cases, however, analyses were finally made of all feeding stuffs used, so that the calculations of the nutrients in the rations as published are based upon the results of the actual analyses of the feeds used and weights fed in the different tests. The chief uncertainty as to the actual amount of digestible nutrients per cow per day lies in the factors used for computing digestibility of the nutrients in the different materials. So far as possible, these were taken from results of actual digestion experiments with materials similar to those that were fed in the tests, but in case no experiments had been made with such material, the factors used were those for other material of a like character.

#### SUMMARY OF TESTS FROM 1892 TO 1897 INCLUSIVE.

The results of the tests made during five winters from November, 1892, to March, 1897, were discussed in some detail in the report of this Station for 1897 (pp. 17-66). The results may be briefly summarized in this connection on account of their bearing upon the studies here reported.

The studies included tests with thirty-two different herds. In each case a study was made in which the ration was that regularly fed by the farmer; and in thirteen cases a second study of the herd was made shortly after the first, in which a different ration, proposed by the Station, was used. Thus the total number of tests made up to 1897 was forty-five.

For convenience, the thirty-two tests in which the ration was that ordinarily fed have been divided into two groups according to the proportion of digestible protein in the ration. The first group is comprised of those herds receiving ordinarily less than two pounds of digestible protein per cow per day, and the second group those receiving more than two pounds. In the first group there are included sixteen herds, with a total of 226 cows. The average amount of digestible protein per cow per day was 1.62 pounds, and the nutritive ratio was 1 to 8.1. The average daily milk and butter production were 16.3 and .87 pounds respectively. The second group also includes sixteen herds, with 227 cows. The average amount of digestible



protein per cow per day was 2.32 pounds and the nutritive ratio 1 to 5.9. The average daily milk and butter production were 18.7 and 1.05 pounds, respectively.

With thirteen herds including 156 cows a second test was made in which a ration was proposed by the Station, and was intended to be richer in protein. In one of these tests the ration was not acceptable to the cows, and in another it was so nearly like the first ration as to be practically the same. Omitting the data for these two herds and comparing the results of the first and second tests with the eleven other herds it was found that the average amount of protein per cow per day was 1.78 pounds in the first test and 2.40 pounds in the second test. The nutritive ratio was 1 to 7.7 in the former and 1 to 5.1 in the latter. As regards the milk flow and yield of butter, there was a slight increase during the second test in spite of the fact that the cows were from one to four weeks further advanced in the period of lactation. The average cost of the ration was also reduced about 6 per cent. in the second test, in spite of the increased amount of protein fed. If the manurial value of the rations is taken into account the ration richer in protein was still more economical as compared with the lower ration found in actual use. While it would not be fair to claim that these differences in the results with the smaller and larger amounts of protein are due wholly to the character of the ration, there seems to be evidence that the ration had considerable to do with the final results.

#### FEEDING ACCORDING TO MILK PRODUCTION.

In earlier experiments the ration fed during the second test was based upon the weight of the cow, the general aim being to feed two and one-half pounds digestible protein to 1,000 pounds live weight where the cow gave an average milk flow. The studies made by this Station, however, as well as those of other experiment stations in this country and Europe, indicated that the quantity of protein in the ration should be based rather upon the milk production than upon the weight of the cow; so that a small cow giving a large amount of milk should perhaps receive more digestible protein than a larger cow with a smaller milk flow. With a uniform milk production variations of from one to two hundred pounds live weight do not

seem to call for differences in the amounts of food, but an increased milk flow calls for a larger ration, more especially a larger amount of digestible protein, in order to meet the increased demands on the system of the animal.

This subject was discussed in the Report of this Station for 1897 (pp. 119-129) and rations were proposed for feeding cows according to the milk yield. It was suggested tentatively that for a milk yield under twenty pounds per day there should be given a basal ration furnishing about two pounds of digestible protein, while for every five pounds increase in the daily milk yield there should be added one pound of protein mixture furnishing approximately a third of a pound of digestible protein.

#### EXPERIMENTS DURING THE WINTERS OF 1897-8 AND 1898-9.

In order to study the value of rations for milch cows based upon milk yields, preliminary experiments were put in operation during the seasons 1897-1899. These experiments were made with three different herds, but various unavoidable circumstances rendered the results unsatisfactory, so that they have not been published. So far as they show anything, however, they point to a fact that had already been recognized, namely, that ordinarily the rations should be increased rather in proportion to the increase of total solids in the milk than to total milk yield. It would be somewhat difficult, of course, for the dairyman or farmer to determine readily the amount of solids in milk; but an approximate measure of the variations in the total solids may be found in the variations in the amount of butter fat in the milk, since the quantity of the other solid ingredients (casein, sugar and ash) remains fairly constant in ordinary milk; that is to say, a variation in total solids of milk is ordinarily due to a variation in butter fat rather than in the other ingredients.

#### PLAN OF EXPERIMENTS DURING THE WINTER OF 1899-1900.

In the winter of 1899-1900 tests were made with four herds to study the effect of feeding according to the yield of total solids in the milk as measured by the amount of butter fat. These experiments are reported in detail in the following pages. Each experiment consisted of two tests. In the first test the herd was fed according to the usual practice of the dairyman,

and the amounts and composition of the feeds used and of the milk produced were determined. It was found that generally a uniform grain ration was fed to all the cows in a herd, although in some cases it was varied in amount somewhat according to the yields of milk.

In the second test the ration was proposed by the Station, and was determined for each herd by the production of butter fat by the cows in the herd. The cows were arranged in groups according to the average daily amount of butter fat produced by each cow during the first test, and all the cows in a group were fed uniformly. The ration consisted of two parts: a basal ration and an additional grain ration. The basal ration was made up of coarse fodders and grain feeds in various proportions, the whole intended to furnish 2.0 pounds of digestible protein. The additional grain feed was made up of different concentrated feeding stuffs mixed together in various proportions depending on composition. This for convenience is called a "protein mixture," and was planned to furnish .3 pound of digestible protein for every pound of mixture. All the cows in the test were given the same basal ration, but the amount of protein mixture added to it depended upon the amount of butter fat the cows had produced.

The arrangement of the cows in groups, and the ration for each group, during the second test were as follows:

Group A. Cows producing .50 to .65 pound of butter fat (.58 to .76 lb. butter) per day were given the basal ration alone, intended to furnish 2.00 pounds of digestible protein.

Group B. Cows producing .66 to .80 pound of butter fat (.77 to .93 lb. butter) per day were given the basal ration and 1 pound of protein mixture, the whole intended to furnish 2.30 pounds of digestible protein.

Group C. Cows producing .81 to .95 pound of butter fat (.94 to 1.11 lbs. butter) per day were given the basal ration and 2 pounds of protein mixture, the whole intended to furnish 2.60 pounds of digestible protein.

Group D. Cows producing .96 to 1.10 pounds of butter fat per day (1.12 to 1.28 lbs. butter) were given the basal ration and 3 pounds of protein mixture, the whole intended to furnish 2.90 pounds of digestible protein.

The basal ration was made up largely of such coarse fodders as were grown on the farm, to which were added grain feeds composed largely of materials that did not contain a very large proportion of protein. The plan was to feed this ration to all the cows in the test, irrespective of the yields of milk or of butter fat. The ration used was one which might be called medium-wide, having a nutritive ratio of about 1:6. It was intended to furnish a nearly constant amount of digestible protein per day for each cow, and this was to be used as a basis upon which to increase the protein for the more productive cows. The basal ration varied somewhat in the different experiments as regards the actual amount of digestible protein, but was generally uniform for all cows in any particular test. The protein mixture which was added to the basal ration for part of the cows was composed mainly of feeding stuffs relatively high in protein.

The herds studied and the tests made during the winter of 1899-1900 were lettered and numbered consecutively with those of preceding years. They are designated as Herd P, tests 51 and 53; Herd Q, tests 52 and 54; Herd R, tests 55 and 57, and Herd S, tests 56 and 58. The data obtained in these tests are given in the tables below. The more important details, with summaries of the results, are given in the discussion of the individual tests on pages 148-155.

#### DETAILED DATA OF DAIRY HERD TESTS OF 1899-1900.

The analyses of all the different material used in the rations in these tests are given in the article on Analyses of Fodders and Feeding Stuffs on a preceding page. From these analyses and the amounts of the materials used the amounts of digestible nutrients in the rations were calculated by use of certain factors, called coefficients of digestibility, which represent the proportions of the total nutrients that are digestible. The coefficients of the digestibility of the separate feeding stuffs as given in Table 32 below are based upon the results of actual experiments with animals, mainly those of American experiments but in some cases European. The coefficients for the grain mixtures are calculated from the factors for the different ingredients and the proportions in which they are used in the mixtures.



TABLE 32.

*Coefficients of digestibility employed in calculating the digestible nutrients in the different feeding stuffs used in these rations.*

KIND OF FEEDING STUFFS.	Protein.	Fat.	Nitrogen-free extract.	Fiber.
	%	%	%	%
* Corn silage, - - - - -	52	79	70	67
* Hungarian hay, - - - - -	60	64	67	68
* Hay, mixed grasses, - - - - -	58	48	59	60
* Rowen hay, - - - - -	69	48	64	66
* Oat and pea hay, - - - - -	60	60	54	66
* Corn stover, - - - - -	45	62	61	67
* Oat straw, - - - - -	53	61	52	44
* Cream gluten meal, - - - - -	84	98	88	33
† Atlantic gluten meal, - - - - -	77	78	74	26
* Chicago gluten meal, - - - - -	89	93	93	33
* Wheat middlings, - - - - -	79	87	81	33
† Provender, - - - - -	77	83	82	27
† Acme wheat feed, - - - - -	77	78	74	26
* Buffalo gluten feed, - - - - -	86	87	84	66
* Cotton seed meal, - - - - -	88	93	64	32
* Wheat bran, - - - - -	77	69	68	20
† H. O. dairy feed, - - - - -	78	84	77	26
* Ground oats, - - - - -	78	84	77	26
* Corn and cob meal, - - - - -	76	82	84	28
† Grain mixture used in test No. 52, - - - - -	85	87	77	35
† Grain mixture No. 1 used in test No. 54, - - - - -	84	80	78	22
† Grain mixture No. 2 used in test No. 54, - - - - -	87	92	83	33
† Grain mixture No. 1 used in test No. 53, - - - - -	81	79	72	26
† Grain mixture No. 2 used in test No. 53, - - - - -	87	92	80	33
† Grain mixture used in test No. 55, - - - - -	83	83	82	29
† Grain mixture No. 1 used in test No. 57, - - - - -	84	87	78	38
† Grain mixture No. 2 used in test No. 57, - - - - -	87	92	78	49
† Grain mixture used in test No. 56, - - - - -	82	78	77	37
† Grain mixture No. 1 used in test No. 58, - - - - -	81	81	80	22
† Grain mixture No. 2 used in test No. 58, - - - - -	85	94	87	58

The fuel values of the rations were computed by multiplying the number of pounds of digestible protein and carbohydrates by 1,860 and the number of pounds of digestible fat by 4,220 and taking the sum of the products as representing the number of calories of available energy in the ration.

\* See Report Storrs Experiment Station for 1897, A Study of Rations fed to Milch Cows, p. 22; and Nitrogenous Feeding Stuffs, p. 83.

† Assumed.

† Computed from the assumed digestibility of the ingredients used in the grain mixture.



The prices of the food materials used in calculating the cost of the ration were those current during the winter of 1899-1900. Those of the feeding stuffs were averages of prices for ton lots quoted to the Station by dealers in several different cities in the state. Those for coarse fodders were based upon the market value of the various materials as estimated by the farmers themselves.

In estimating the values of the manure obtainable from the different rations it was assumed that 75 per cent. of the nitrogen, phosphoric acid and potash of the fodders and feeding stuffs may be saved in the manure.\* The valuations per pound assumed for these ingredients were those estimated by the New England Experiment Stations for 1899-1900.†

The following table shows the average market price of a ton of any of the different feeding stuffs used, and the estimated value of the manure obtainable from it.

TABLE 33.

*Valuation of feeding stuffs as used in rations fed milch cows in winter 1899-1900.*

KIND OF FEEDING STUFFS.	Market price per ton of feeding stuffs.	Estimated value of the manure obtainable from one ton of feeding stuffs.
Cream gluten meal, - - - - -	\$24.00	\$12.50
Atlantic gluten meal, - - - - -	23.00	13.00
Chicago gluten meal, - - - - -	24.00	13.00
Wheat middlings, - - - - -	19.00	7.00
Provender, - - - - -	19.00	5.00
Acme wheat feed, - - - - -	19.00	8.00
Buffalo gluten feed, - - - - -	19.00	8.00
Cotton seed meal, - - - - -	26.00	19.00
Wheat bran, - - - - -	18.00	8.00
H. O. dairy feed, - - - - -	23.00	8.00
Ground oats, - - - - -	22.00	7.00
Corn and cob meal, - - - - -	14.00	4.00
Hungarian hay, - - - - -	14.00	4.00
Hay, mixed grasses, - - - - -	18.00	4.00
Rowen hay, - - - - -	15.00	5.00
Oat and pea hay, - - - - -	12.00	5.00
Corn stover, - - - - -	6.00	3.00
Corn silage, - - - - -	3.00	1.00
Oat straw, - - - - -	6.00	2.00

\* See Rept. Storrs Sta. 1897, pp. 92-93.

† See page 38 of the present Report.

The data obtained in the dairy herd tests during the winter of 1899-1900 are given in detail in Tables 34-41 below. For each herd there are two tables. The first table gives the following statistics for each cow in the herd: The breed, age and estimated weight; the number of months since last calf and, where known, the time when due; the minimum, maximum and average daily yield of milk, percentage of fat in each day's milk, and daily yield of butter fat, for both the first and second tests. The names of the different breeds as given in the second column are abbreviated as follows: A=Ayrshire; D=Durham; Gy=Guernsey; H=Holstein; J=Jersey. The letter G before the initial of a breed signifies that the cow was a grade.

The data in the second table give the average daily ration per cow, as calculated for the whole herd in the first test, and for the number of cows in each group in the second test. They show the weights of coarse and concentrated feeds in the ration, the amounts of digestible nutrients they were estimated to furnish, their fuel value, nutritive ratio, total cost, and net cost as corrected for the value of the manure.



## AVERAGE DAILY RATION. HERD P.

Test No. 51. Hay of mixed grasses 7.7 lbs., corn silage 29.9 lbs., wheat bran 3.0 lbs., wheat middlings 5.7 lbs., and Chicago gluten meal 3.0 lbs.

Test No. 53. Basal: Oat and pea hay 8.3 lbs., corn silage 31.3 lbs; and 8.7 lbs. of grain feeds mixed as follows; wheat bran 1,000 lbs., wheat middlings 400 lbs., cotton seed meal 200 lbs., Chicago gluten meal 100 lbs. Additional grain feed: Group B, 1.2 lbs., Group C, 2.1 lbs., and Group D, 2.8 lbs. of the following mixture; cotton seed meal 200 lbs., Chicago gluten meal 125 lbs., wheat middlings 100 lbs.

TABLE 35.

*Average weight of food and digestible nutrients fed per cow per day, with fuel value and cost, in dairy herd tests Nos. 51 and 53.*

[Average weight of herd 800 lbs.]

KIND OF FOOD.	Amount fed per day.	DIGESTIBLE NUTRIENTS AND FUEL VALUE.						Nutritive ratio.	Cost.	Value of obtainable manure.	Net cost.
		Protein.	Fat.	CARBOHYDRATES.			Fuel value.				
				Nitrogen-free extract.	Fiber.	Total.					
	Lbs.	Lbs.	Lbs	Lbs.	Lbs.	Lbs.	Cal.	1:	Cts.	Cts.	Cts.
FIRST TEST NO. 51.											
Whole Herd.											
Concentrated food,	11.7	2.13	.41	4.93	.27	5.20	15360	2.9	11.7	5.2	6.5
Coarse food, -	37.6	.58	.25	5.19	2.60	7.79	16630	14.4	10.7	3.3	7.4
Total food, -	49.3	2.71	.66	10.12	2.87	12.99	31990	5.3	22.4	8.5	13.9
SEC'ND TEST NO. 53.											
Group A.											
Concentrated food,	8.7	1.46	.36	3.07	.20	3.27	10320	2.8	8.5	3.9	4.6
Coarse food, -	39.6	.87	.28	5.16	2.92	8.08	17830	10.0	9.7	4.1	5.6
Total food, -	48.3	2.33	.64	8.23	3.12	11.35	28150	5.5	18.2	8.0	10.2
Group B.											
Concentrated food,	9.9	1.84	.44	3.44	.22	3.66	12090	2.5	9.9	4.7	5.2
Coarse food, -	39.6	.87	.28	5.16	2.92	8.08	17830	10.0	9.7	4.1	5.6
Total food, -	49.5	2.71	.72	8.60	3.14	11.74	29920	4.9	19.6	8.8	10.8
Group C.											
Concentrated food,	10.8	2.12	.52	3.71	.23	3.94	13460	2.4	11.0	5.4	5.6
Coarse food, -	39.6	.87	.28	5.16	2.92	8.08	17830	10.0	9.7	4.1	5.6
Total food, -	50.4	2.99	.80	8.87	3.15	12.02	31290	4.6	20.7	9.5	11.2
Group D.											
Concentrated food,	11.5	2.35	.56	3.92	.24	4.16	14470	2.3	11.9	5.9	6.0
Coarse food, -	39.6	.87	.28	5.16	2.92	8.08	17830	10.0	9.7	4.1	5.6
Total food, -	51.1	3.22	.84	9.08	3.16	12.24	32300	4.4	21.6	10.0	11.6





## AVERAGE DAILY RATION. HERD Q.

Test No. 52. Hay of mixed grasses 6.2 lbs., rowen hay 7.2 lbs., Hungarian hay 5.6 lbs., corn stover 4.5 lbs., and 3.8 lbs. of grain feeds mixed as follows: wheat bran 9.5 lbs., provender 12.5 lbs., H. O. dairy feed 13.5 lbs., cotton seed meal 21.5 lbs., Buffalo gluten feed 19.5 lbs.

Test No. 54. Basal: Hay of mixed grasses 7.0 lbs., rowen hay 7.4 lbs., corn stover 4.8 lbs., and 5 lbs. of grain feed mixed as follows: Provender 100 lbs., wheat bran 200 lbs., Chicago gluten meal 125 lbs. Additional grain feed: Group C, 2 lbs. of the following mixture: Cotton seed meal 100 lbs., Chicago gluten meal 125 lbs. and wheat middlings 100 lbs.

TABLE 37.

*Average weight of food and digestible nutrients fed per cow per day, with fuel value and cost, in dairy herd tests Nos. 52 and 54.*

[Average weight of herd 750 lbs.]

KIND OF FOOD.	Amount fed per day.	DIGESTIBLE NUTRIENTS AND FUEL VALUE.						Nutritive ratio.	Cost.	Value of obtainable manure.	Net cost.	
		Protein.	Fat.	CARBO-HYDRATES.			Fuel value.					
				Nitrogen-free extract.	Fiber.	Total.						
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Cal.	1:	Cts.	Cts.	Cts.
FIRST TEST NO. 52.		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Cal.	1:	Cts.	Cts.	Cts.
<i>Whole Herd.</i>												
Concentrated food, -	3.8	.83	.19	1.37	.11	1.48	5100	2.3	4.0	2.6	1.4	
Coarse food, -	24.6	1.40	.37	6.10	4.40	10.50	23700	8.2	15.5	4.9	10.6	
Total food, -	28.4	2.23	.56	7.47	4.51	11.98	28800	6.0	19.5	7.5	12.0	
SECOND TEST NO. 54.												
<i>Group A.</i>												
Concentrated food, -	5.0	.85	.18	2.07	.08	2.15	6340	3.0	5.0	2.8	2.2	
Coarse food, -	20.2	1.14	.30	5.03	3.42	8.45	19100	8.0	12.8	4.1	8.7	
Total food, -	25.2	1.99	.48	7.10	3.50	10.60	25440	5.9	17.8	6.9	10.9	
<i>Group C.</i>												
Concentrated food, -	7.0	1.46	.30	2.77	.10	2.87	9320	2.4	7.4	4.6	2.8	
Coarse food, -	20.3	1.14	.30	4.96	3.44	8.40	19010	8.0	12.9	4.1	8.8	
Total food, -	27.3	2.60	.60	7.73	3.54	11.27	28330	4.6	20.3	8.7	11.6	

TABLE 38.  
Statistics of herd R during tests Nos. 55 and 57.

Rel. No.	Cows. Group and Breed.	Age.	Weight. Lbs.	Mos. since last calf.	Due.	TEST NO. 55. JAN. 30 TO FEB. 10, 1900.						TEST NO. 57. MARCH 1-12, 1900.					
						DAILY MILK FLOW.			DAILY PCTG. FAT.			DAILY MILK FLOW.			DAILY PCTG. FAT.		
						Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
		Yrs.		Mos.		Lbs.	Lbs.	%	%	%	%	Lbs.	Lbs.	%	%	Lbs.	%
<i>Group A.</i>																	
1	G. J.	10	950	11	Unknown, -	9.7	12.0	10.6	6.0	6.6	6.2	.65	10.9	12.3	11.8	5.8	6.3
7	G. H.	3	600	4	Not, -	16.8	20.8	18.5	3.2	3.6	3.4	.57	.76	.63	19.6	21.3	20.6
9	G. J.	5	600	5	Sept., 1900,	12.8	14.3	13.6	3.4	3.8	3.6	.44	.57	.49	12.9	15.1	13.9
11	G. J.	3	550	3	Oct., 1900,	18.0	20.6	19.1	1.2	7.3	0.2	.9	.49	.62	.55	16.4	20.4
13	G. J.	5	650	4	Oct., 1900,	11.0	12.5	11.4	5.4	5.8	5.6	.61	.71	.64	11.4	12.8	12.2
15	G. D.	12	850	6	Not, -	11.5	13.3	12.1	4.0	4.9	4.5	.47	.61	.55	11.0	12.3	11.6
16	G. J.	7	750	10	July, 1900,	11.6	13.8	12.9	4.3	5.5	5.0	.52	.75	.63	10.8	12.5	11.6
17	G. A.	18	1300	8	Not, -	9.0	13.9	12.1	3.4	5.3	4.2	.31	.74	.52	9.7	10.8	10.1
	Average,	—	780	—	—	—	13.8	—	4.4	—	—	—	13.8	—	4.8	—	—
<i>Group B.</i>																	
3	G. J.	9	700	7	Unknown, -	10.8	15.2	13.3	4.9	6.2	5.5	.53	.84	.73	12.9	14.7	13.6
4	G. J.	15	650	5	Not, -	12.9	14.9	13.7	4.8	5.8	5.2	.62	.84	.72	13.7	15.0	14.8
5	G. J.	4	600	4	Not, -	14.9	19.0	17.0	5.2	6.4	5.6	.75	1.08	.94	14.7	20.8	19.0
6	G. J.	3	600	3	Not, -	13.4	15.2	14.3	3.5	3.8	3.6	.71	.85	.80	14.7	16.2	15.5
8	G. J.	3	550	4	Oct., 1900,	11.5	15.4	13.5	5.5	6.6	6.1	.76	.89	.82	13.6	15.5	14.4
10	G. G.	5	700	3	Not, -	10.5	15.8	13.5	4.9	6.0	5.3	.34	.79	.68	13.8	15.9	15.0
	Average,	—	630	—	—	—	14.2	—	5.6	—	—	—	15.4	—	5.7	—	—
<i>Group C.</i>																	
2	J. A.	9	900	5	Sept., 1900,	18.3	21.6	20.0	4.6	5.0	4.8	.88	1.08	.96	19.5	21.9	20.5
12	G. J.	12	900	1	Not, -	21.4	23.8	22.6	3.4	3.8	3.6	.78	.87	.82	23.8	26.0	25.2
14	G. H.	7	900	1	Not, -	27.5	30.4	29.2	2.6	3.1	2.9	.77	.88	.83	28.9	36.8	34.2
18	G. J.	5	650	3	Not, -	16.0	21.0	18.2	5.0	5.6	5.3	.86	1.13	.98	18.0	20.7	19.6
	Average,	—	840	—	—	—	22.5	—	4.2	—	—	—	24.9	—	4.6	—	—
	Herd Average,	—	750	—	—	—	15.9	—	4.8	—	—	—	16.8	—	5.1	—	—

## AVERAGE DAILY RATION. HERD R.

Test No. 55. Hay of mixed grasses 8.5 lbs., corn silage 27.5 lbs., and 6.2 lbs. of grain feeds mixed as follows: ground wheat 190 lbs., Buffalo gluten feed 160 lbs., and provender 150 lbs.

Test No. 57. Basal, (with slight variations in amounts of coarse fodder for the different groups): Hay of mixed grasses 29-31 lbs., corn silage 6.0-6.9 lbs., corn stover 2 lbs., and 7.4 lbs. of grain feeds mixed as follows: mixed wheat feed 200 lbs., Buffalo gluten feed 200 lbs., provender 200 lbs., and cotton seed meal 150 lbs. Additional grain feeds: Group B, 1 lb., and Group C, 2 lbs. of a mixture of equal parts Buffalo gluten feed and cotton seed meal.

TABLE 39.

*Average weight of food and digestible nutrients fed per cow per day, with fuel value and cost, in dairy herd tests Nos. 55 and 57.*

[Average weight of herd 750 lbs.]

KIND OF FOOD.	Amounts fed per day.	DIGESTIBLE NUTRIENTS AND FUEL VALUE.						Nutritive ratio.	Cost.		Value of obtainable manure.	Net cost.
		Protein.	Fat.	CARBO-HYDRATES.			Fuel value.					
				Nitrogen-free extract.	Fiber.	Total.						
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Cal.	1:	Cts.	Cts.	Cts.	
FIRST TEST NO. 55.												
Whole Herd.												
Concentrated food, -	6.2	.86	.22	3.03	.11	3.14	8370	4.2	5.9	2.2	3.7	
Coarse food, -	36.0	.63	.32	6.00	2.81	8.81	18900	15.1	10.9	3.4	7.5	
Total food, -	42.2	1.49	.54	9.03	2.92	11.95	27270	8.8	16.8	5.6	11.2	
SECOND TEST NO. 57.												
Group A.												
Concentrated food, -	7.4	1.60	.32	2.78	.13	2.91	9740	2.3	7.4	3.8	3.6	
Coarse food, -	37.7	.49	.29	4.80	2.88	7.68	16420	17.0	10.0	3.4	6.6	
Total food, -	45.1	2.09	.61	7.58	3.01	10.59	26160	5.7	17.4	7.2	10.2	
Group B.												
Concentrated food, -	8.4	1.95	.38	3.05	.16	3.21	11200	2.1	8.5	4.6	3.9	
Coarse food, -	37.0	.47	.29	4.68	2.80	7.48	16010	17.3	9.8	3.2	6.6	
Total food, -	45.4	2.42	.67	7.73	2.96	10.69	27210	5.0	18.3	7.8	10.5	
Group C.												
Concentrated food, -	9.4	2.30	.45	3.32	.18	3.50	12690	2.0	9.6	5.3	4.3	
Coarse food, -	40.0	.52	.32	5.10	3.06	8.16	17500	17.1	10.8	3.6	7.2	
Total food, -	49.4	2.82	.77	8.42	3.24	11.66	30190	4.7	20.4	8.9	11.5	



## AVERAGE DAILY RATION. HERD S.

Test No. 56. Hay of mixed grasses 15.2 lbs., corn stover 7.4 lbs. and 4.8 lbs. of grain feeds mixed as follows: wheat bran 200 lbs., Buffalo gluten feed 180 lbs., and corn and cob meal 85 lbs.

Test No. 58. Basal: Hay of mixed grasses 10.2 lbs., corn stover 6.5 lbs., and 7.0 lbs. of a mixture of equal parts of wheat bran, corn and cob meal and cream gluten meal. Additional grain feeds: Group B, 1 lb., and Group C, 2 lbs. of a mixture of cream gluten meal 200 lbs. and Buffalo gluten feed 100 lbs.

TABLE 41.

*Average weight of food and digestible nutrients fed per cow per day, with fuel value and cost, in dairy herd tests Nos. 56 and 58.*

[Average weight of herd 725 lbs.]

KIND OF FOOD.	Amounts fed per day.		DIGESTIBLE NUTRIENTS AND FUEL VALUE.						Nutritive ratio.	Cost.		Value of obtainable manure.	Net cost.
			Protein.	Fat.	CARBO-HYDRATES.			Fuel value.					
					Nitrogen-free extract.	Fiber.	Total.						
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Cal.	1:	Cts.	Cts.	Cts.		
FIRST TEST NO. 56.													
Whole Herd.													
Concentrated food, -	4.8	.71	.16	2.01	.14	2.15	5990	3.5	4.2	1.7	2.5		
Coarse food, -	22.6	.74	.30	6.13	3.90	10.03	21300	14.5	14.4	4.1	10.3		
Total food, -	27.4	1.45	.46	8.14	4.04	12.18	27290	9.1	18.6	5.8	12.8		
SECOND TEST NO. 58.													
Group A.													
Concentrated food, -	7.0	1.11	.19	3.24	.06	3.30	9000	3.4	6.3	2.8	3.5		
Coarse food, -	16.7	.70	.28	4.76	2.77	7.53	16490	11.7	10.2	2.9	7.3		
Total food, -	23.7	1.81	.47	8.00	2.83	10.83	25490	6.6	16.5	5.7	10.8		
Group B.													
Concentrated food, -	8.0	1.36	.21	3.70	.08	3.78	10450	3.1	7.4	3.3	4.1		
Coarse food, -	16.7	.70	.28	4.76	2.77	7.53	16490	11.7	10.2	2.9	7.3		
Total food, -	24.7	2.06	.49	8.46	2.85	11.31	26940	6.0	17.6	6.2	11.4		
Group C.													
Concentrated food, -	9.0	1.61	.24	4.16	.10	4.26	11930	3.0	8.5	3.8	4.7		
Coarse food, -	16.7	.70	.28	4.76	2.77	7.53	16490	11.7	10.2	2.9	7.3		
Total food, -	25.7	2.31	.52	8.92	2.87	11.79	28420	5.6	18.7	6.7	12.0		



## DISCUSSION OF THE TESTS.

*Herd P. Tests Nos. 51 and 53.*—Thirteen cows in this herd were included in this experiment, the same ones in both tests. Ten of the cows were Jerseys or grade Jerseys, and one was a grade Guernsey; these were estimated to weigh between 650 and 900 pounds each. The two other cows were grade Durhams, weighing not far from 1100 pounds each. Most of the cows were giving a good flow of milk, none being due to calve in less than three months after the close of the second test. The herd was well stabled, and watered from a trough in a protected yard with a southerly exposure, in which the cows were allowed to exercise a short time each day during pleasant weather. The coarse fodders used consisted of hay and corn silage. The hay was first quality early cut hay of mixed grasses, and was eaten without waste; the corn silage was made of corn harvested when the ears were beginning to glaze. The grain feeds used were wheat bran, wheat middlings and Chicago gluten meal.

The first test with this herd began December 4, 1899, and continued twelve days. In this test the average daily ration for each cow consisted of between seven and eight pounds of hay, about thirty pounds of corn silage, and between eleven and twelve pounds of mixed grain feeds. The average amount of digestible protein in the ration was 2.7 pounds daily. The ration was a narrow one, having a nutritive ratio of 1:5.3.

There was an interval of seventeen days between the two tests. The second test began January 2, 1900, and continued eleven days. In the ration proposed for this test, oat and pea hay was substituted for the hay of mixed grasses used in the first test, the proportion of wheat bran used was considerably increased, and cotton seed meal was added to the ration. The average basal ration for each cow in the herd consisted of about eight pounds of oat and pea hay, thirty pounds of corn silage and between eight and nine pounds of mixed grain feeds. This ration was planned to furnish two pounds of digestible protein per day, but according to the analyses there was really 2.3 pounds.

There were three groups of cows that received the mixed grain feeds called protein mixture in addition to the basal ration. In the first group there was one cow, which had one

pound; in the second group seven cows had two pounds each; in the third group three cows had three pounds each. There was .3 pound of digestible protein in each pound of the mixture. In this way the quantity of protein fed was regulated by the productiveness of the cow.

TABLE 42.

*Summarized results with Herd P; tests Nos. 51 and 53.*

[First test Dec. 4-16, 1899. Second test Jan. 2-13, 1900.]

	DIGESTIBLE NUTRIENTS AND FUEL VALUE.					AV. DAILY YIELD.		Cost of ration.	Cost of 100 lbs. milk.	Cost of 1 lb. butter.
	Protein.	Fat.	Carbo- hydrates.	Fuel Value.	Nutritive ratio.	Milk.	Butter.			
	Lbs.	Lbs.	Lbs.	Cal.	1:	Lbs.	Lbs.	Cts.	\$	Cts.
Group A, 2 cows:										
1st test, - - -	2.71	.66	12.99	31990	5.3	10.3	.65	22.4	2.17	34.5
2d test, - - -	2.33	.64	11.35	28150	5.5	9.1	.62	18.2	2.00	29.4
Group B, 1 cow:										
1st test, - - -	2.71	.66	12.99	31990	5.3	11.7	.90	22.4	1.91	24.9
2d test, - - -	2.71	.72	11.74	29920	4.9	11.9	.99	19.6	1.65	19.8
Group C, 7 cows:										
1st test, - - -	2.71	.66	12.99	31990	5.3	15.5	.97	22.4	1.44	23.1
2d test, - - -	2.99	.80	12.02	31290	4.6	15.0	.99	20.7	1.38	20.9
Group D, 3 cows:										
1st test, - - -	2.71	.66	12.99	31990	5.3	25.2	1.37	22.4	.89	16.3
2d test, - - -	3.22	.84	12.24	32300	4.4	25.0	1.39	21.6	.86	15.5
Average of herd, 13 cows:										
1st test, - - -	2.71	.66	12.99	31990	5.3	16.6	1.01	22.4	1.35	22.2
2d test, - - -	2.92	.79	11.95	30935	4.7	16.2	1.03	20.4	1.26	20.0

Comparing the data obtained in the two tests, as summarized in Table 42, it will be observed that for the whole herd the average daily cost of the ration in the first test was 22.4 cents, and in the second test 20.4 cents, while the average daily milk flow was 16.6 pounds in the first test and 16.2 pounds in the second, and the average daily yield of butter was 1.01 pounds in the first test and 1.03 in the second. The cost of producing 100 pounds of milk was 9 cents less, while the cost of producing one pound of butter was 2.2 cents less, in the second test than in the first. A comparison of the data for the different groups of cows in the second test, which were given rations differing according to the yields of butter fat, with the data for the same group of cows as fed in the first test shows

the relative economy of feeding according to the yields of butter fat. In every case the cost of producing 100 pounds of milk, or one pound of butter, was less with the groups in the second test than with the corresponding cows in the first test.

*Herd Q. Tests Nos. 52 and 54.*—This was a small, well managed herd. Eight cows were used in the tests, the same cows in both tests. They were all grade Jerseys, estimated to range in weight from 625 to 850 pounds and to average about 750 pounds. Most of the cows had calved within six months of the beginning of the first test, and none were due to calve until more than four months after the close of the second test. The cows were fed a large variety of feeds. The coarse fodders used were home grown, of good quality, consisting of early cut hay, rowen hay, Hungarian hay, corn stover and oat straw, the latter being fed only in small quantities. The grain feeds included H. O. dairy feed, provender (ear-corn and oats ground together), spring wheat bran, cotton seed meal and Buffalo gluten feed.

The first test began December 18, 1900, and continued twelve days. In this test all the cows in the herd were fed the same ration. Each cow received a rather heavy feeding of coarse fodders, about twenty-five pounds per day, and a rather light feeding of grain feeds, about four pounds per day. The different varieties of both coarse and concentrated fodders mentioned above were used in about the same proportions each day. With this ration each cow was receiving about 2.2 pounds of digestible protein daily.

After an interval of sixteen days the second test was begun on January 15, 1901, and continued twelve days. In the basal ration for this test the amount of coarse fodder was reduced to about 20 pounds per day for each cow, by omitting the Hungarian hay, the supply of which was exhausted, and feeding the other fodders in about the same quantities as in the first test. At the same time the amount of grain feed was increased to about 5 pounds per day for each cow. With this basal ration each cow received about 2.0 pounds of digestible protein per day.

There were two groups of cows in this test. The three cows in the first group received the basal ration alone, but the cows in the second group received in addition 2 pounds of the protein mixture, which increased the digestible protein in their ration to 2.6 pounds per day.

The table which follows gives a comparison between the results obtained with corresponding groups of cows in the first and the second tests. In the first test both the groups were fed alike; in the second test the amount of protein in the ration was regulated by the production of butter fat. On the average for the whole herd, however, the amount and proportion of the digestible nutrients did not vary widely in the two rations, although the second ration had a somewhat narrower nutritive ratio. The average daily yield of milk with the first ration was 13.9 pounds, and with the second ration 16.3 pounds, while the daily yield of butter was .88 pounds with the first and .98 pounds with the second ration. The daily cost of the second ration was practically the same as that of the first, while the average cost of 100 pounds of milk was 21 cents less, and the cost of a pound of butter was 2.4 cents less, with the second ration than with the first.

TABLE 43.

*Summarized results with Herd Q; tests Nos. 52 and 54.*

[First test Dec. 18-30, 1899. Second test Jan. 15-27, 1900.]

	DIGESTIBLE NUTRIENTS AND FUEL VALUE.					AV. DAILY YIELD.		Cost of ration.	Cost of 100 lbs. milk.	Cost of 1 lb. butter.
	Protein.	Fat.	Carbo- hydrates.	Fuel Value.	Nutritive ratio.	Milk.	Butter.			
	Lbs.	Lbs.	Lbs.	Cal.	1:	Lbs.	Lbs.	Cts.	\$	Cts.
Group A, 3 cows:										
1st test, - - -	2.23	.56	11.98	28800	6.1	10.5	.70	19.5	1.86	27.9
2d test, - - -	1.99	.48	10.60	25440	5.9	11.6	.74	17.8	1.53	24.0
Group B, 5 cows:										
1st test, - - -	2.23	.56	11.98	28800	6.1	16.0	.98	19.5	1.22	19.9
2d test, - - -	2.60	.60	11.27	28330	4.6	19.1	1.12	20.3	1.06	18.1
Average of herd, 8 cows:										
1st test, - - -	2.23	.56	11.98	28800	6.1	13.9	.88	19.5	1.40	22.2
2d test, - - -	2.37	.56	11.02	27250	5.2	16.3	.98	19.4	1.19	19.8

The differences between the yields in the two tests were probably not due entirely to the differences in rations. During the first test most of the cows of the herd were attacked with diarrhoea for two or three days, and one for a longer period.



By this disturbance the yields of milk were considerably reduced, although the percentages of fat in the milk were somewhat higher, so that the yields of butter fat were not much affected. However, when the yields for the period preceding this disturbance in the first test are compared with those for a similar period in the second test there was still a slight increase in the latter.

*Herd R. Tests Nos. 55 and 57.*—This herd was kept mainly for milk production, although it had produced cream for a local creamery and most of the cows were of the butter type. Eighteen cows were used in these tests, the same cows in both tests. Twelve of the cows were grade Jerseys, two were grade Ayrshires, two were grade Holsteins, one was a grade Guernsey and one a grade Durham. The estimated average weight of the cows was 750 pounds. Most of the cows had calved between one and six months previous to the beginning of the first test, although two had been milking ten and eleven months at the time of the first test. None of them were due to calve until about four months after the close of the second test. The herd was well stabled and each cow had a constant supply of water available in her stall. The cows were not allowed to run in the yard, being housed all of the winter. There were no irregularities in the general health of the cows, and all the feeds were well eaten.

The coarse fodder used consisted of hay, corn stover and corn silage; the hay was first quality meadow hay of mixed grasses; the stover was of good quality; the corn silage was made from corn harvested when the ears were just past the milk stage. The grain feeds used were wheat feed, Buffalo gluten feed, provender (corn and oats ground) and cotton seed meal.

The first test began January 30, 1899, and continued twelve days. The average daily ration for each cow was about 8 pounds of hay, 27 pounds of corn silage and 6 pounds of mixed grain feeds. This ration supplied only about 1.5 pounds of digestible protein per day, and had a wide nutritive ratio, 1:8.8.

The second test began February 28, 1900, and continued twelve days. In this ration the amount of hay fed was slightly reduced, and corn stover was added. Cotton seed meal was



also added to the grain feeds used, and the proportions of Buffalo gluten feed and provender were slightly increased. The average basal ration for each cow in the herd consisted of 6 to 7 pounds of hay, about 2 pounds of corn fodder, 29 to 31 pounds of corn silage, and about 7.5 pounds of mixed grain feeds. This ration supplied about 2.1 pounds of digestible protein per day, and had a nutritive ratio of 1:5.1.

One group of eight cows were given only this basal ration. One group of six cows received the basal ration and in addition 1 pound of protein mixture for each cow, increasing the digestible protein to 2.4 pounds per day; and another group of four cows received 2 pounds of protein mixture in addition to the basal ration, making the total digestible protein for each cow in this group 2.8 pounds per day.

TABLE 44.

*Summarized results with Herd R; tests Nos. 55 and 57.*

[First test Jan. 30-Feb. 10, 1900. Second test March 1-12, 1900.]

	DIGESTIBLE NUTRIENTS AND FUEL VALUE.					AV. DAILY YIELD.		Cost of ration.	Cost of 100 lbs. milk.	Cost of 1 lb. butter.
	Protein.	Fat.	Carbo- hydrates.	Fuel Value.	Nutritive ratio.	Milk.	Butter.			
	Lbs.	Lbs.	Lbs.	Cal.	1:	Lbs.	Lbs.	Cts.	\$	Cts.
Group A, 8 cows:										
1st test, - - -	1.49	.54	11.95	27270	8.8	13.8	.68	16.8	1.22	24.7
2d test, - - -	2.09	.61	10.59	26160	5.7	13.8	.75	17.4	1.26	23.2
Group B, 6 cows:										
1st test, - - -	1.49	.54	11.95	27270	8.8	14.2	.91	16.8	1.18	18.5
2d test, - - -	2.42	.67	10.69	27210	5.0	15.4	1.03	18.3	1.19	17.8
Group C, 4 cows:										
1st test, - - -	1.49	.54	11.95	27270	8.8	22.5	1.05	16.8	.75	16.0
2d test, - - -	2.82	.77	11.66	30190	4.7	24.9	1.26	20.4	.82	16.2
Average of herd, 18 cows:										
1st test, - - -	1.49	.54	11.95	27270	8.8	15.9	.84	16.8	1.06	20.0
2d test, - - -	2.36	.67	10.86	27400	5.2	16.8	.96	18.4	1.09	19.2

The results of the tests are summarized in Table 44. By comparing the cost of the rations fed, and the values of the products obtained, in the groups which were fed different rations in the second test with those in the same groups fed uniform rations in the first test, the relative economy of the different rations may be seen. The average yield of milk in

the first test was 15.9 pounds, and in the second test was 16.8 pounds; and the average yield of butter was .84 pounds in the first test and .96 in the second. The first ration cost 16.8 cents and the second ration 18.4 cents. The average cost of producing 100 pounds of milk was \$1.06 in the first test and \$1.09 in the second, while the cost of a pound of butter was 20 cents in the first test and 19.2 cents in the second. From these figures it will be seen that while the average cost of the rations was 1.6 cents higher in the second test, the cost of producing 100 pounds of milk was slightly higher, and the cost of producing 1 pound of butter was slightly lower in the second test than in the first.

*Herd S. Tests Nos. 56 and 58.*—This was a small herd used in producing cream for a coöperative creamery. The herd was well stabled in a new barn and was driven a short distance each day to get water in a yard connected with another barn. Nine cows were included in each of these tests, the same ones in both tests. Seven of the cows were grade Jerseys, one a grade Holstein and one a grade Ayrshire. The average estimated weight of the cows in the herd was 725 pounds. Two of the cows had aborted during the summer and fall of 1899 and one had calved prematurely, by about one month, shortly before the first test; but all of the animals seemed to be in a fair state of health at the time the test was begun, and there were no irregularities in the experiment.

The coarse fodder used consisted of early cut hay of mixed grasses and corn stover, which were eaten with practically no waste. The grain feeds were wheat bran, Buffalo gluten feed, cream gluten meal and corn and cob meal.

The first test began February 12, 1900, and continued twelve days. The daily ration for each cow in this test consisted of about 15 pounds of hay and 7 to 8 pounds of corn stover with about 5 pounds of mixed grain feeds. This ration supplied about 1.5 pounds of digestible protein per day, and had a nutritive ratio of 1:9.1.

The second test began March 12, 1900, and continued twelve days. In this test the amount of coarse fodders used was reduced, but the amount of grain feeds was increased. The average basal ration for each cow consisted of about 10 pounds

of hay, 6.5 pounds of corn stover, and 7 pounds of mixed grain feeds. This ration supplied about 1.8 pounds of digestible protein per day, and had a nutritive ratio of 1:6.6.

One group of four cows received only this basal ration. Another group of four cows received the basal ration and for each cow an additional feeding of 1 pound of protein mixture, increasing the digestible protein to 2.1 pounds per day. The single cow in the third group received the basal ration and 2 pounds of protein mixture, supplying 2.3 pounds of digestible protein per day.

A comparison of the results with the groups of cows fed according to the yields of butter fat in the second test and those with the same groups having an average ration in the first test is shown in the following table. For the whole herd the cost of the ration averaged 18.6 cents in the first test and 17.2 cents in the second. The average daily milk flow in the first test was 13.5 pounds and in the second test 16.7 pounds, while the average daily yield of butter was .78 pounds in the first test and 1.03 in the second. The average cost of producing 100 pounds of milk was 35 cents less and the cost of a pound of butter 7 cents less in the second test than in the first test.

TABLE 45.

*Summarized results with Herd S; tests Nos. 56 and 58.*

[First test Feb. 12-24, 1900. Second test March 12-24, 1900.]

	DIGESTIBLE NUTRIENTS AND FUEL VALUE.					AV. DAILY YIELD.		Cost of ration.	Cost of 100 lbs. milk.	Cost of 1 lb. butter.
	Protein.	Fat.	Carbo- hydrates.	Fuel Value.	Nutritive ratio.	Milk.	Butter.			
	Lbs.	Lbs.	Lbs.	Cal.	1:	Lbs.	Lbs.	Cts.	\$	Cts.
Group A, 4 cows:										
1st test, - - -	1.45	.46	12.18	27290	9.1	11.3	.69	18.6	1.65	27.0
2d test, - - -	1.81	.47	10.83	25490	6.6	14.2	.88	17.6	1.24	20.0
Group B, 4 cows:										
1st test, - - -	1.45	.46	12.18	27290	9.1	14.4	.81	18.6	1.29	23.0
2d test, - - -	2.06	.49	11.31	26940	6.0	17.7	1.09	16.5	.93	15.1
Group C, 1 cow:										
1st test, - - -	1.45	.46	12.18	27290	9.1	18.6	1.09	18.6	1.00	17.1
2d test, - - -	2.31	.52	11.79	28420	5.6	22.9	1.39	18.7	.82	13.4
Average of herd, 9 cows:										
1st test, - - -	1.45	.46	12.18	27290	9.1	13.5	.78	18.6	1.38	23.8
2d test, - - -	1.98	.48	11.15	26460	6.2	16.7	1.03	17.2	1.03	16.7

## SUMMARY.

*Four herds of cows were studied during the winter of 1899 and 1900. Two tests were made with each herd, covering periods of 11 or 12 days. In the first test the entire herd was fed a ration which was essentially the same for each cow; while in the second test the ration was varied according to the yields of butter fat. Two grain mixtures were used in the second test. The first, together with the coarse fodder used, was called a basal ration, which was planned to contain not far from 2 pounds of digestible protein daily. The actual amounts of digestible protein in the basal ration varied from 1.80 to 2.30 pounds. The second grain mixture was called a protein mixture. It was usually composed of the feeding stuffs which the farmer was using, combined in such proportions as to furnish approximately .3 of a pound of digestible protein for each pound of the mixture.*

*The plan of feeding in the second test was to use the basal ration for all the cows in the test, and to add to this varying quantities of the protein mixture according to the yields of butter fat, as shown by the results of the first test. Those cows producing from .50 to .65 pound of butter fat in the first test received the basal ration only; those producing from .66 to .80 pound of butter fat received one pound of the protein mixture in addition to the basal ration; those producing from .81 to .95 pound of butter fat received 2 pounds of the protein mixture in addition to the basal ration; while those producing .96 to 1.10 pounds of butter fat received 3 pounds of the protein mixture in addition to the basal ration.*

*A comparison of the results of the two tests with each of the four herds is given in the following table. The figures are averages for the total number of cows in each test.*

*In three of the experiments the average cost of the ration used in the second test was less than that of the one used in the first test. The cost of producing 100 pounds of milk was also less in the second test of the same three experiments, while the cost of producing 1 pound of butter was less in all cases.*

*The economy of feeding according to the yield of milk or of butter fat will depend much upon what yields are taken as a basis in feeding. In these experiments there was used about 2 pounds of digestible protein for .50 to .65 pound of butter fat, and the*



protein was increased by .3 pound for an increase of .15 pound in the yield of fat. In the cases of three herds this plan of feeding proved more profitable than the one of feeding a nearly uniform ration to all the cows.

TABLE 46.

*Summary of daily rations fed, and daily milk and butter yield.*

HERD.	Average weight of cows.	Number of test.	DAILY RATION PER HEAD.					AVERAGE DAILY		COST OF FOOD TO PRODUCE			
			Digestible protein.	Fuel value of digestible nutrients.	Nutritive ratio.	Total cost.	* Net cost.	Milk flow.	† Yield of butter.	100 lbs. Milk.		1 lb. Butter.	
										Total cost.	*Net cost.	Total cost.	*Net cost.
	Lbs.		Lbs.	Cal.	1:	Cts.	Cts.	Lbs.	Lbs.	\$	Ct.	Ct.	Ct.
P, { 1st test, }	800	51	2.71	31990	5.3	22.4	13.9	16.6	1.01	1.35	83	22	14
{ 2d test, }		53	2.92	30950	4.7	20.4	11.1	16.2	1.03	1.26	69	20	11
Q, { 1st test, }	750	52	2.23	28800	6.0	19.5	12.0	13.9	.88	1.40	86	22	14
{ 2d test, }		54	2.37	27250	5.2	19.4	11.3	16.3	.98	1.19	69	20	12
R, { 1st test, }	750	55	1.49	27270	8.8	16.8	11.2	15.9	.84	1.06	70	20	13
{ 2d test, }		57	2.36	27400	5.2	18.4	10.6	16.8	.96	1.09	63	19	11
S, { 1st test, }	725	56	1.45	27290	9.1	18.6	12.8	13.5	.78	1.38	95	24	16
{ 2d test, }		58	1.98	20460	6.2	17.2	11.2	16.7	1.03	1.03	67	17	11

The experiments, as a whole, help to verify the earlier work of this Station, and point out the economy of feeding a larger proportion of protein than most farmers are in the habit of feeding. Rations supplying from 1.80 to 2.60 pounds of digestible protein per day, according to the yields of milk or of butter fat, have generally proven more profitable than those furnishing less protein.

\* Total cost less value of obtainable manure.

† On the assumption that the amount of butter that can be made is equivalent to seven-sixths of the amount of butter fat produced.



## POT EXPERIMENTS WITH NITROGENOUS FERTILIZERS.

BY C. S. PHELPS.

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During the past twelve years the Station has conducted experiments on the effects of nitrogenous fertilizers upon the yields of some of our common farm crops, and especially upon the proportions of nitrogen in them. The crops grown in these experiments have included some of the legumes, as clover and soy beans, cereal crops, such as corn and oats, and many of our common grasses; in general, such crops as are commonly used for feeding dairy stock, the chief object being to determine the effects of fertilizer nitrogen in different forms and quantities upon the feeding value of the crop.

Previous to 1898 these investigations were made chiefly in the field, upon the plots of the special nitrogen experiments, as explained in the Reports of the Station from year to year. Several difficulties have been met with in these experiments, which are quite common to field experiments in general. Chief among these are, first, the difficulty of finding soil of a uniform quality for all plots; second, the variation in season, especially in the amount of rainfall; and third, the difficulty of using the fertilizers so that the crop will get the full benefit of them and at the same time not get plant food in varying amounts from other sources.

Since 1898 experiments for the study of the effect of nitrogenous fertilizers upon the proportion of nitrogen in plants have also been made on a small scale in such a way that various external influences that might affect the growth of the plants may be somewhat regulated. The plants that have been used are oats, Hungarian grass, orchard grass and soy beans. These are grown in pots by the use of the same kinds and proportions of nitrogenous and mineral fertilizers as are used in the field experiments, the purpose of the pot experiments being to verify the results obtained in the field experiments, and to

ascertain if more uniform results may be obtained where the conditions of soil, moisture and fertilizer are more nearly under control.

*Pots used.*—In these experiments the plants are grown in galvanized iron pots 18.5 inches deep and 10 inches in diameter. These pots hold from 60 to 80 pounds of the soil, sand and gravel used. Each pot is fitted outside with a half-inch pipe, entering about an inch from the bottom, for use in watering the plants.

*Soil used.*—The soil used in these experiments was taken from plots on the field used for special nitrogen experiments. The mineral plots were selected, for the reason that nothing but mineral fertilizers—phosphoric acid and potash—had been applied to them since 1890. There seemed to be but a small amount of organic matter in the soil, and judging from the crops that had been grown on it, there was but little nitrogen available for plant food. In order to make the soil more or less uniform in character it was hauled into a pile and thoroughly mixed.

*Filling the pots and adding the fertilizers.*—In filling the pots medium coarse gravel was put in at the bottom to the depth of about two inches, and this was covered with a layer of sand. About an inch of soil was put on this and lightly pressed with a tamper about the diameter of the pots, then a little more soil was added and tamped, and so on till the pot was full. The soil was then allowed to settle. In all the experiments up to 1900, 10 pounds of gravel and sand and 50 pounds of soil per pot were used in each of the series of experiments when the pots were first prepared for use. In the soy bean experiments for 1900, 10 pounds of gravel and sand and 56 pounds of soil were used in each pot. As the moisture in the soil doubtless differed the second year from what it was the first year, in cases where the same soil was used the second time, the actual weights of dry soil may have differed for the two years. But as the conditions under which the soil was stored for the winter were uniform the quantity of moisture in the soil of each of the pots of a series would have been essentially the same when the second year's experiments were started, as it was in the first year.

In adding the fertilizers to the soil of the pots about eight inches of the soil was removed from the top of each pot and with this the fertilizers were thoroughly mixed. The soil containing the fertilizer was then replaced as before and lightly pressed.

The quantities of fertilizer applied to the soils were calculated to be proportional to those used in the plot experiments. Some of the pots received the mineral fertilizers only—phosphoric acid 1 gram, potash 1.5 grams and lime (calcium oxid) 2 grams in each pot; some pots received these mineral fertilizers and a little more than 3 grams of nitrogen in each, called the one-third nitrogen ration; some received the mineral fertilizers and twice as much nitrogen as the preceding, called the two-thirds ration; and some received the full ration of nitrogen, about 9.5 grams, in addition to the minerals. The nitrogen was in all cases supplied in nitrate of soda.

*Shelter and care of plants.*—The building used for a plant shelter is a light frame structure, 20 x 25 feet in area, open to the ridge and provided with a large number of windows. On one side there is a small addition which serves as a storage room for soil and small tools and as a work room. The floor is of earth, and is about on a level with the small yard on the west side of the building. Extending through the length of the building and about 30 feet into the yard are three tracks on which are placed small, low trucks with light board platforms, to carry the pots of soil in which the plants are grown. At the end of and at right angles to the main tracks there is a sunken track, with a low truck the top of which is level with the main tracks. This low truck is used in transferring the regular trucks with the growing plants from one track to another. By this means it is possible to make the average exposure to sunlight about the same for each lot of plants; whereas if the trucks remained on the same track all through the season some of the larger plants might intercept the sunlight from the smaller ones.

During pleasant weather the plants were kept outside the building; but during stormy weather, and whenever the wind might be likely to break the plants, they were housed in the plant shelter.

If the greater part of the water used was poured on the surface of the soil in the pots it might dissolve out the nitrogenous fertilizers as it percolated through the soil, and carry them to the bottom of the pots and perhaps out of the immediate vicinity of the roots of the plants. To avoid this as much as possible, the plants were watered mainly from the bottom of the pots, by means of the pipe on the outside. The water used was taken from a driven well at the College, as analysis had shown this water to be practically free from nitrogen. The water was supplied to the plants as it seemed to be needed to keep up a vigorous growth. The need of water was seldom shown by the wilting of the plants, which would seem to indicate that the quantity supplied was sufficient for normal growth.

*Sampling and analyzing the crops.*—When the crops were ready to harvest the total growth on each pot was cut about one inch above the soil and in each case (except the straw of the soy beans) the total crop was taken for a sample. In the oat experiments the seeds were separated from the straw after the sample was thoroughly air-dried, and the loose hulls were added to the straw, the seeds and the straw being analyzed separately. In the experiments with Hungarian grass and those with orchard grass the crops were harvested in the early seed stage and the samples included the total amount of fodder from each pot. In the soy bean experiments only the seeds were sampled, no effort being made to save the stems and leaves, as it had been found in field experiments that many of the leaves dropped off before the seeds were fully matured. All of the crops were thoroughly air-dried and kept in sealed glass jars until prepared for analysis.

The only analyses of the crops from the pot experiments were determinations of nitrogen, as these were sufficient for the purpose of the experiments. The total nitrogen was determined by the Kjeldahl method. Nitric nitrogen was also determined in a number of samples, as described in a preceding article on the Analyses of Fodders and Feeding Stuffs (page 83).

The data in the tables below for the experiments with different crops show for each pot the amount of nitrogen in the fertilizer, the total weight of crop produced, the percentage and total weight of nitrogen and the estimated percentage of protein.



The total weight of nitrogen is calculated from the weight of crop and the percentage of total nitrogen determined. A comparison of the amounts of total nitrogen in the same crop from different pots with varying amounts of fertilizer nitrogen gives an indication of how much the nitrogen in the crop increased as the nitrogen in the fertilizer was increased. It will be observed that as the moisture content of the sample at the time of analysis was not determined the comparison must be made between the amounts of nitrogen determined in air-dried fodders, that is, in the condition in which they are ordinarily used. Past experience has shown, however, that different samples of the same fodder when thoroughly air-dried under similar conditions differ but slightly in moisture content, the differences being hardly sufficient to affect materially the determination of the proportions of protein. For practical purposes, therefore, the comparison of the proportions of nitrogen as determined in the air-dried samples is sufficiently accurate.

To compare the effects of the different amounts of fertilizer nitrogen upon the feeding value of the crops, the percentage of protein in the crops from the different pots was estimated by the usual method, by multiplying the percentage of nitrogen by the factor 6.25, on the assumption that protein contains 16 per cent. nitrogen. This method of course is not absolutely correct, as pointed out on a preceding page (p. 39). For instance, not all forms of protein contain 16 per cent. nitrogen. On the other hand, a portion of the total nitrogen of some crops may frequently be in the form of nitrates, because when readily available nitrates are abundant in the soil they may be taken up by plants more rapidly than they can be built up into plant tissue, and may thus be present unchanged in considerable amounts,\* especially if the plant is harvested in premature stages of growth. These nitrates are of no value as food for animals. As shown in Table 19 on page 84, some of the crops in these pot experiments contained appreciable amounts of nitrates, which would affect to some extent the proportions of actual protein present as determined by the usual method. However, the method used for estimating protein is perhaps sufficiently accurate for practical purposes; and since it has been and is still commonly used, it has also been followed in this case.

\* See Connecticut Sta. Rept. 1895, p. 108.



## DISCUSSION OF THE EXPERIMENTS.

On the following pages is given the discussion of the experiments with oats and Hungarian grass in 1898, with Hungarian grass, orchard grass and soy beans in 1899, and with soy beans in 1900. A number of other experiments besides these were made during the three years, but the growth in most cases was so poor that it was believed the results would be abnormal and therefore it would not be advisable to make the analyses.

The oat experiments of 1898 comprised twelve pots; all the other experiments reported comprised sixteen pots. In each experiment, the total number of pots used was made up of an equal number of those with mineral fertilizer only and those with the one-third, two-thirds and full rations of nitrogen in addition to the minerals. All the pots of the same kind formed a group, the results for the individual pots in each group being averaged together.

## EXPERIMENT WITH OATS, 1898.

This experiment included pots Nos. 1 to 12, with three pots fertilized alike comprising a group. In general the growth on the different pots was not so heavy in the case of the oats as it was on corresponding pots in the Hungarian grass and the orchard grass experiments described below. The crop was fairly uniform, however, on pots which were similarly fertilized with nitrogen. Samples were taken October 20, 1898. The crop was cut about an inch above the soil, and the total amount on each pot was taken for a sample. When the crop was thoroughly air-dry the seeds were separated from the straw and chaff, and later the two were analyzed separately. The results of this experiment are given in the table below.

*Oat seeds.*—There was a gradual increase in the percentages of nitrogen and of protein in the crops of different pots in accordance with the quantities of nitrogen supplied in the fertilizer. The increase in the percentage of nitrogen in the oat seeds was much more marked than the increase in yield.

*Oat straw.*—With the exception of the crop on pot 6 the growth was quite uniform on all the pots which were similarly fertilized with nitrogen. Omitting the results from pot 6 the

yields of straw increased gradually with the quantities of nitrogen supplied in the fertilizer. As in the case of the oat seeds, however, the increase in the percentages of nitrogen in the crops from the pots having larger quantities of nitrogen was much more marked than the increase in yields.

TABLE 47.

*Nitrogen in fertilizer and in crop in pot experiments with oats, 1898.*

Lab. No.	Pot No.	SAMPLE.	FERTILIZER.					Total weight of crop.	Total nitrogen.		Total protein (N. $\times$ 6.25).
			Kind.	Amt. of nitro- gen per pot.							
					Gms	Gms	%	Gm	%		
6365	1	Oat seeds, -	Minerals only, - - -	—	8.5	2.37	.20	14.81			
6367	2	Oat seeds, -	Minerals only, - - -	—	7.0	2.39	.17	14.94			
6369	3	Oat seeds, -	Minerals only, - - -	—	9.5	2.39	.23	14.94			
		Average, -			8.3	2.38	.20	14.90			
6371	4	Oat seeds, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	11.0	2.54	.28	15.88			
6373	5	Oat seeds, -	Minerals + $\frac{1}{4}$ nit. ration, -	3.17	9.0	2.87	.25	17.94			
6375	6	Oat seeds, -	Minerals + $\frac{1}{2}$ nit. ration, -	3.17	13.5	2.71	.26	16.94			
		Average, -			11.2	2.71	.26	16.92			
6377	7	Oat seeds, -	Minerals + $\frac{3}{8}$ nit. ration, -	6.34	13.0	2.74	.36	17.13			
6379	8	Oat seeds, -	Minerals + $\frac{1}{2}$ nit. ration, -	6.34	11.5	2.76	.32	17.25			
6381	9	Oat seeds, -	Minerals + $\frac{5}{8}$ nit. ration, -	6.34	14.5	2.84	.41	17.75			
		Average, -			13.0	2.78	.36	17.38			
6383	10	Oat seeds, -	Minerals + full nit. ration,	9.51	13.5	2.82	.38	17.63			
6385	11	Oat seeds, -	Minerals + full nit. ration,	9.51	13.5	2.77	.37	17.31			
6387	12	Oat seeds, -	Minerals + full nit. ration,	9.51	9.5	2.83	.27	17.69			
		Average, -			12.2	2.81	.34	17.54			
6366	1	Oat straw, -	Minerals only, - - -	—	11.5	1.03	.12	6.44			
6368	2	Oat straw, -	Minerals only, - - -	—	18.5	.76	.14	4.75			
6370	3	Oat straw, -	Minerals only, - - -	—	18.5	.72	.13	4.50			
		Average, -			16.1	.83	.13	5.18			
6372	4	Oat straw, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	33.0	1.20	.39	7.50			
6374	5	Oat straw, -	Minerals + $\frac{1}{4}$ nit. ration, -	3.17	36.5	1.20	.44	7.50			
6376	6	Oat straw, -	Minerals + $\frac{1}{2}$ nit. ration, -	3.17	12.5	.98	.12	6.13			
		Average, -			27.3	1.13	.32	7.05			
6378	7	Oat straw, -	Minerals + $\frac{3}{8}$ nit. ration, -	6.34	31.5	1.28	.40	8.00			
6380	8	Oat straw, -	Minerals + $\frac{1}{2}$ nit. ration, -	6.34	39.0	1.26	.49	7.88			
6382	9	Oat straw, -	Minerals + $\frac{5}{8}$ nit. ration, -	6.34	36.0	1.25	.45	7.81			
		Average, -			35.5	1.26	.45	7.90			
6384	10	Oat straw, -	Minerals + full nit. ration,	9.51	41.5	1.34	.56	8.38			
6386	11	Oat straw, -	Minerals + full nit. ration,	9.51	32.5	1.19	.39	7.44			
6388	12	Oat straw, -	Minerals + full nit. ration,	9.51	38.0	1.42	.54	8.88			
		Average, -			37.3	1.32	.50	8.23			

## EXPERIMENTS WITH HUNGARIAN GRASS, 1898.

This experiment included pots Nos. 17 to 32, with four pots in each group. It will be seen from the table below that the total yields of crop in this experiment were quite uniform from pots with similar amounts of nitrogen. The total range in yields per pot in the group with mineral fertilizers was only from 28.0 to 33.5 grams; in the group with the lowest (one-third) ration of nitrogen the range was 50.5 to 54.0 grams; in the group with the second (two-thirds) ration of nitrogen the range was 55.0 to 59.0 grams and in that with the largest (full) ration the range was 54.0 to 61.0 grams. Fairly uniform results were also obtained in the percentages of nitrogen for the crops from the different pots which were fertilized

TABLE 48.

*Nitrogen in fertilizer and in crop in pot experiments with Hungarian grass, 1898.*

Lab. No.	Pot No.	SAMPLE.	FERTILIZER.		Amt. of nitro- gen per pot.	Total weight of crop.	Total nitrogen.		Total protein (N. $\times$ 6.25).	
			Kind.							
					Gms	Gms	%	Gms	%	
1984	17	Hungarian grass,	Minerals only,	-	-	—	32.0	1.05	.34	6.56
1985	18	Hungarian grass,	Minerals only,	-	-	-	31.5	1.10	.35	6.88
1986	19	Hungarian grass,	Minerals only,	-	-	—	28.0	1.11	.31	6.94
1987	20	Hungarian grass,	Minerals only,	-	-	—	33.5	1.13	.38	7.06
		Average, -					<b>31.3</b>	<b>1.10</b>	<b>.35</b>	<b>6.86</b>
1988	21	Hungarian grass,	Minerals + $\frac{1}{3}$ nit. ration,			3.17	50.5	1.40	.71	8.75
1989	22	Hungarian grass,	Minerals + $\frac{1}{3}$ nit. ration,			3.17	53.5	1.40	.75	8.75
1990	23	Hungarian grass,	Minerals + $\frac{1}{3}$ nit. ration,			3.17	53.0	1.35	.72	8.44
1991	24	Hungarian grass,	Minerals + $\frac{1}{3}$ nit. ration,			3.17	54.0	1.35	.73	8.44
		Average, -					<b>52.8</b>	<b>1.38</b>	<b>.73</b>	<b>8.60</b>
1992	25	Hungarian grass,	Minerals + $\frac{2}{3}$ nit. ration,			6.34	56.0	1.67	.94	10.44
1993	26	Hungarian grass,	Minerals + $\frac{2}{3}$ nit. ration,			6.34	59.0	1.85	1.09	11.56
1994	27	Hungarian grass,	Minerals + $\frac{2}{3}$ nit. ration,			6.34	55.0	1.77	.97	11.06
1995	28	Hungarian grass,	Minerals + $\frac{2}{3}$ nit. ration,			6.34	56.0	1.85	1.04	11.56
		Average, -					<b>56.5</b>	<b>1.79</b>	<b>1.01</b>	<b>11.16</b>
1996	29	Hungarian grass,	Min'ls + full nit. ration,			9.51	54.0	2.10	1.13	13.13
1997	30	Hungarian grass,	Min'ls + full nit. ration,			9.51	58.0	1.94	1.13	12.13
1998	31	Hungarian grass,	Min'ls + full nit. ration,			9.51	61.0	1.92	1.17	12.00
1999	32	Hungarian grass,	Min'ls + full nit. ration,			9.51	60.0	1.81	1.09	11.31
		Average, -					<b>58.3</b>	<b>1.94</b>	<b>1.13</b>	<b>12.14</b>

alike. The only case of a considerable variation from the other samples was in that from pot 21 which showed a considerably lower percentage of nitrogen than the other samples from the same group. The percentages of nitrogen in the crops of the pots in the different groups varied markedly with the amounts of nitrogen used. The average percentage in the crop where the largest quantity of nitrogen used was nearly twice as large as the average where no nitrogen was used in the fertilizer. Of course corresponding differences are seen in percentages of protein.

#### EXPERIMENTS WITH HUNGARIAN GRASS, 1899.

The experiment on Hungarian grass in 1899 was a repetition of the experiment of 1898 in the same lot of pots and without change of soil. The soil was taken from each pot and sifted to remove the roots, after which it was returned to the pot from which it came, and then fertilizer was added in the same manner as in the previous year.

Samples were taken August 17, 1899. The plants were in bloom when harvested. The total crop from each pot was cut off about one inch above the soil, then cut up into pieces about a half an inch long, and hung in loose paper bags in the plant house to dry.

On the pots with mineral fertilizers the growth was rather slender, mostly stem, and pale reddish-yellow in color; on the pots with the small amount of nitrogen there was a fair crop, with a medium amount of leaf growth, slightly yellow in color; on the pots with the medium amount of nitrogen the crop was quite heavy, with a large amount of leaf growth, and of good color; on the pots with the large nitrogen ration there was a heavy crop with thick leaf growth and dark green in color.

From a comparison of the results in the table below with those in Table 48 it will be observed that the average yield of fodder per pot in the different groups was not as large as in 1898, but in most cases was fairly uniform from pots having the same amounts of nitrogen, and the relative increase in the yield from pots with the larger rations of nitrogen was much the same for the two years. Why the total yield on the various pots was so much less the second year than the first is not evident unless it is that an excess of nitrogen in the soil had a deleterious effect on the growth of the plants (see page 174).



Although the total yield was smaller the second year, the percentages of nitrogen in the crops on corresponding groups were higher in 1899 than in 1898. The higher percentage of nitrogen found in 1899 may have been due to the influence of the fertilizer nitrogen left over from the previous year which was taken up by the crop of the second season, or it may have been due to the acquisition by the plants of a relatively larger proportion of the nitrogen used as a fertilizer when the smaller growth occurred.

TABLE 49.

*Nitrogen in fertilizer and in crop in pot experiments with Hungarian grass, 1899.*

Lab. No.	Pot No.	SAMPLE.	FERTILIZER.				Total weight of crop.		Total nitrogen.	Total protein (N. X 6.25).	
			Kind.	Amt. of nitro- gen per pot.	Total weight of crop.	Total nitrogen.					
							Gms	Gs			%
6204	17	Hungarian grass,	Minerals only,	-	-	-	—	19	1.20	.23	7.50
6205	18	Hungarian grass,	Minerals only,	-	-	-	—	21	1.28	.27	8.00
6206	19	Hungarian grass,	Minerals only,	-	-	-	—	12	1.72	.21	10.75
6207	20	Hungarian grass,	Minerals only,	-	-	-	—	19	1.19	.23	7.44
		Average,	-					18	1.35	.24	8.42
6208	21	Hungarian grass,	Minerals + $\frac{1}{3}$ nit. ration,	-	3.08	20	1.87	.37	11.69		
6209	22	Hungarian grass,	Minerals + $\frac{1}{3}$ nit. ration,	-	3.08	18	1.80	.32	11.25		
6210	23	Hungarian grass,	Minerals + $\frac{1}{3}$ nit. ration,	-	3.08	20	1.80	.36	11.25		
6211	24	Hungarian grass,	Minerals + $\frac{1}{3}$ nit. ration,	-	3.08	17	1.74	.30	10.88		
		Average,	-			19	1.80	.34	11.27		
6212	25	Hungarian grass,	Minerals + $\frac{2}{3}$ nit. ration,	-	6.16	28	2.05	.57	12.81		
6213	26	Hungarian grass,	Minerals + $\frac{2}{3}$ nit. ration,	-	6.16	23	1.97	.45	12.31		
6214	27	Hungarian grass,	Minerals + $\frac{2}{3}$ nit. ration,	-	6.16	26	1.89	.48	11.81		
6215	28	Hungarian grass,	Minerals + $\frac{2}{3}$ nit. ration,	-	6.16	24	2.06	.49	12.88		
		Average,	-			25	1.99	.50	12.45		
6216	29	Hungarian grass,	Minerals + full nit. ration,	-	9.24	28	2.12	.59	13.25		
6217	30	Hungarian grass,	Minerals + full nit. ration,	-	9.24	26	2.16	.56	13.50		
6218	31	Hungarian grass,	Minerals + full nit. ration,	-	9.24	30	2.07	.62	12.94		
6219	32	Hungarian grass,	Minerals + full nit. ration,	-	9.24	21	2.25	.47	14.06		
		Average,	-			26	2.15	.56	13.44		

## EXPERIMENT WITH ORCHARD GRASS, 1899.

The experiment with orchard grass, pots 33 to 48, was started in 1899, with sods taken from the plots in the grass garden which for six years received mineral fertilizers only. The first



crop of grass was harvested in good condition, and a second or rowen crop was then produced from the same pots, but without a second application of fertilizer. Table 50 gives the data for this experiment.

*First crop.*—The growth of grass seemed to be normal throughout the season. The samples of the first crop were taken July 1, 1899, when most of the heads were past bloom and the earliest plants were beginning to form seed. The total crop from each pot was cut off about an inch above the soil, then cut into pieces about a half an inch long and dried in the steam drier.

The variation in weight of the total crop was small for all pots of a group. The growth seemed heavy on all the pots, but was especially so on the pots of the group having the larger rations of nitrogen. On the pots with mineral fertilizers there was a rather slender growth, pale yellow in color; on the pots with the smallest (one-third) nitrogen ration the growth was fairly heavy, with medium amount of leaf, and slightly pale green in color; on the pots with the medium (two-thirds) nitrogen ration the growth was quite heavy, quite thickly leaved at the bottom, and of good color; on the pots with the full nitrogen ration there was a heavy growth with leaves thick at the bottom and of dark green color.

The average percentage of nitrogen in the crop from the pots on which the largest ration of nitrogen was used was more than twice as high as that in the crop from the mineral pots, where no nitrogen was used. This, of course, affected in the same proportion the percentages of protein. This experiment illustrates very forcibly the possibility of increasing the feeding value of our common grasses by the liberal use of nitrogenous fertilizers.

*Second or rowen crop.*—The orchard grass rowen was sampled November 10, 1899. The pots had been under shelter since September 20. The grass was considerably dried and brown when harvested. Crop was cut off just above the soil and was cut into pieces about an inch long and dried.

The second growth of orchard grass appeared to be nearly normal, although there were considerable differences between the groups of pots to which different quantities of nitrogen

TABLE 50.

*Nitrogen in fertilizer and in crop in pot experiments with orchard grass, 1899.*

Lab. No.	Pot No.	SAMPLE.	FERTILIZER.		Total weight of crop.	Total nitrogen.		Total protein (N. $\times$ 6.25).
			Kind.	Amt. of nitrogen per pot.				
				Gms	Gs	%	Gms	%
<i>Orchard grass.</i>								
6188	33	First crop, -	Minerals only, - - -	—	36	1.56	.56	9.75
6189	34	First crop, -	Minerals only, - - -	—	40	1.56	.62	9.75
6190	35	First crop, -	Minerals only, - - -	—	43	1.69	.73	10.56
6191	36	First crop, -	Minerals only, - - -	—	35	1.57	.55	9.81
		Average, -			<b>39</b>	<b>1.60</b>	<b>.62</b>	<b>9.97</b>
6192	37	First crop, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	46	2.02	.93	12.63
6193	38	First crop, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	47	2.09	.98	13.06
6194	39	First crop, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	48	2.01	.96	12.56
6195	40	First crop, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	45	2.12	.95	13.25
		Average, -			<b>47</b>	<b>2.06</b>	<b>.96</b>	<b>12.88</b>
6196	41	First crop, -	Minerals + $\frac{2}{8}$ nit. ration, -	6.34	59	2.19	1.29	13.69
6197	42	First crop, -	Minerals + $\frac{2}{8}$ nit. ration, -	6.34	54	2.31	1.25	14.44
6198	43	First crop, -	Minerals + $\frac{2}{8}$ nit. ration, -	6.34	46	2.54	1.17	15.88
6199	44	First crop, -	Minerals + $\frac{2}{8}$ nit. ration, -	6.34	56	2.36	1.32	14.75
		Average, -			<b>54</b>	<b>2.35</b>	<b>1.26</b>	<b>14.69</b>
6200	45	First crop, -	Minerals + full nit. ration, -	9.51	51	2.56	1.31	16.00
6201	46	First crop, -	Minerals + full nit. ration, -	9.51	58	2.41	1.40	15.06
6202	47	First crop, -	Minerals + full nit. ration, -	9.51	61	2.46	1.50	15.38
6203	48	First crop, -	Minerals + full nit. ration, -	9.51	61	2.41	1.47	15.06
		Average, -			<b>58</b>	<b>2.46</b>	<b>1.42</b>	<b>15.38</b>
6236	33	Rowen, -	Minerals only, - - -	—	10	1.10	.11	6.88
6237	34	Rowen, -	Minerals only, - - -	—	12	1.18	.14	7.38
6238	35	Rowen, -	Minerals only, - - -	—	11	1.39	.15	8.69
6239	36	Rowen, -	Minerals only, - - -	—	11	1.34	.15	8.38
		Average, -			<b>11</b>	<b>1.25</b>	<b>.14</b>	<b>7.83</b>
6240	37	Rowen, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	14	1.25	.18	7.81
6241	38	Rowen, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	15	1.35	.20	8.44
6242	39	Rowen, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	15	1.23	.18	7.69
6243	40	Rowen, -	Minerals + $\frac{1}{8}$ nit. ration, -	3.17	13	1.42	.14	8.88
		Average, -			<b>14</b>	<b>1.31</b>	<b>.18</b>	<b>8.21</b>
6244	41	Rowen, -	Minerals + $\frac{2}{8}$ nit. ration, -	6.34	16	1.06	.17	6.63
6245	42	Rowen, -	Minerals + $\frac{2}{8}$ nit. ration, -	6.34	16	1.09	.17	6.81
6246	43	Rowen, -	Minerals + $\frac{2}{8}$ nit. ration, -	6.34	16	1.36	.22	8.50
6247	44	Rowen, -	Minerals + $\frac{2}{8}$ nit. ration, -	6.34	19	1.27	.24	7.94
		Average, -			<b>17</b>	<b>1.20</b>	<b>.20</b>	<b>7.47</b>
6248	45	Rowen, -	Minerals + full nit. ration, -	9.51	26	1.11	.29	6.94
6249	46	Rowen, -	Minerals + full nit. ration, -	9.51	23	1.06	.24	6.63
6250	47	Rowen, -	Minerals + full nit. ration, -	9.51	18	1.18	.21	7.38
6251	48	Rowen, -	Minerals + full nit. ration, -	9.51	25	1.10	.28	6.87
		Average, -			<b>23</b>	<b>1.11</b>	<b>.26</b>	<b>6.96</b>

were applied. On the pots supplied with mineral fertilizers only, the plants were small, slender, pale yellow in color, and the total weight of the crop was light; the growth on the pots with the smallest (one-third) nitrogen ration was similar, but slightly heavier. In both these cases the plants had not matured sufficiently to develop flower stalks; while in the next two groups of pots the plants were larger and coarser and more advanced in growth, and the total crop from the pots was heavier. On the pots with the medium (two-thirds) nitrogen ration there was a rather heavy, leafy growth, of fair color; and on the pots with the full ration of nitrogen there was a dense leafy growth, quite heavy and dark green in color.

It will be seen from the data in the table above that the average percentages of nitrogen in the crops of the pots in the group to which the largest quantity of nitrogen was applied were less than was found where smaller amounts or where no nitrogen was used in the fertilizer. This might at first seem to indicate that the crops were unable to utilize the nitrogen left over from the first crop in proportions corresponding to the amounts present. It would seem more probable, however, that the differences in the percentages of nitrogen were due more largely to differences in the degree of maturity of the crops of different pots when harvested. As pointed out above, the growth was far more advanced on the pots to which the larger quantities of nitrogen were applied; the percentages of nitrogen in the crop would probably be less under such conditions. Many analyses of crops harvested in different stages of growth have shown that the younger and less mature the plants when samples are taken for analysis, the larger is the percentage of nitrogen contained in them.

#### EXPERIMENT WITH SOY BEANS, 1899.

The experiment with soy beans, pots 48 to 64, was begun in 1899, with four pots fertilized alike comprising each group. The soil was from the same source as that used in other pot experiments, but in order to insure a growth of tubercles on the roots an infusion of soil and water was made from a field which had grown soy beans for several years, but upon which no nitrogenous fertilizer had been used. The water from this infusion was used several times early in the season in watering

the soil of all the pots in the experiment. When the crops were harvested there was a large number of tubercles on the roots in all the pots.

The samples were taken November 10, 1899. The entire crop of seed from each pot was taken as a sample. The seeds were well dried when harvested; they were shelled from the pods and put into numbered bags.

TABLE 51.

*Nitrogen in fertilizer and in crop in pot experiments with soy bean seed, 1899.*

Lab. No.	Pot No.	SAMPLE.	FERTILIZER.		Total weight of crop.	Total nitrogen.		Total protein (N. $\times$ 6.25).
			Kind.	Amt. of nitrogen per pot.				
				Gms	Gs	%	Gms	%
6220	49	Soy bean seed,	Minerals only, - - -	—	27	6.15	1.66	38.44
6221	50	Soy bean seed,	Minerals only, - - -	—	29	6.21	1.80	38.81
6222	51	Soy bean seed,	Minerals only, - - -	—	25	6.12	1.53	38.25
6223	52	Soy bean seed,	Minerals only, - - -	—	28	6.23	1.74	38.94
		Average, -			<b>27</b>	<b>6.18</b>	<b>1.68</b>	<b>38.61</b>
6224	53	Soy bean seed,	Minerals + $\frac{1}{8}$ nit. ration, -	3.08	15	6.42	.96	40.13
6225	54	Soy bean seed,	Minerals + $\frac{1}{8}$ nit. ration, -	3.08	29	6.25	1.81	39.06
6226	55	Soy bean seed,	Minerals + $\frac{1}{8}$ nit. ration, -	3.08	12	6.34	.76	39.63
6227	56	Soy bean seed,	Minerals + $\frac{1}{8}$ nit. ration, -	3.08	26	6.17	1.60	38.56
		Average, -			<b>28</b>	<b>6.21</b>	<b>1.71</b>	<b>38.81</b>
6228	57	Soy bean seed,	Minerals + $\frac{3}{8}$ nit. ration, -	6.16	29	6.17	1.79	38.56
6229	58	Soy bean seed,	Minerals + $\frac{3}{8}$ nit. ration, -	6.16	33	6.29	2.08	39.31
6230	59	Soy bean seed,	Minerals + $\frac{3}{8}$ nit. ration, -	6.16	20	6.38	1.28	39.88
6231	60	Soy bean seed,	Minerals + $\frac{3}{8}$ nit. ration, -	6.16	31	6.41	1.99	40.06
		Average, -			<b>31</b>	<b>6.29</b>	<b>1.95</b>	<b>39.31</b>
6232	61	Soy bean seed,	Minerals + full nit. ration,	9.24	30	6.33	1.90	39.56
6233	62	Soy bean seed,	Minerals + full nit. ration,	9.24	32	6.47	2.67	40.44
6234	63	Soy bean seed,	Minerals + full nit. ration,	9.24	31	6.20	1.92	38.75
6235	64	Soy bean seed,	Minerals + full nit. ration,	9.24	29	6.50	1.89	40.63
		Average, -			<b>31</b>	<b>6.38</b>	<b>2.10</b>	<b>39.85</b>

The growth on the different pots was quite irregular, owing to the failure of many seeds to germinate. The number of plants per pot, of fairly uniform size and vigorous growth, varied from one to eight. This has made it advisable to omit from the averages results from pots showing abnormal yields. Omitting these it will be seen from the data in Table 51 that



the average yields on the pots of different groups were nearly the same. The results obtained in the total crop seem to be little influenced by the amount of nitrogen in the fertilizer. This was in accord with results obtained with this crop in field experiments with nitrogenous fertilizers.

There was but little variation in the percentage of nitrogen in the crops from the different pots. The average percentage where the largest (full) ration of nitrogen was used was only two-tenths of one per cent. above what was obtained where no nitrogen was used.

These results are in striking contrast with those obtained in the experiment with orchard grass (first crop) and with Hungarian grass. With these latter crops the percentage of nitrogen was sometimes twice as large where the larger amounts of nitrogen were used as where only mineral fertilizers were used.

#### EXPERIMENT WITH SOY BEANS, 1900.

The experiment of 1899 with this crop was repeated in 1900 in the same pots but with a new lot of soil. In this case the soil was taken from field plots which had produced soy beans for five years without the application of nitrogenous fertilizers. A large number of tubercles was found on the roots when the crops were harvested.

The samples were taken October 10, 1900. All the seeds from a pot were taken for a sample. The seeds dried on the stalks before harvesting. The growth was much smaller on the pots as a whole than in the experiment of 1899. Notes taken late in the period of growth show that there was little difference in the appearance of the plants on the different groups of pots. There were six plants in each pot, and the general conditions of growth were nearly the same, except that the plants were somewhat smaller where no nitrogen was used.

The range in the average percentages of nitrogen in the crops from pots of the different groups was from 6.28 per cent. to 6.40 per cent. The differences between the percentages of nitrogen in the crops from pots in the same group, which, of course, were all fertilized alike, were often greater than those between the averages for the groups of pots receiving varying quantities of nitrogen in the fertilizer. The results of this experiment would seem to indicate that with soy beans no



advantage was obtained from the use of nitrogen in the fertilizers, either in the total yields or in the percentage of nitrogen.

TABLE 52.

*Nitrogen in fertilizer and in crop in pot experiments with soy bean seed, 1900.*

Lab. No.	Pot No.	SAMPLE.	FERTILIZER.		Total weight of crop.	Total nitrogen.	Total protein (N. $\times$ 6.25).	
			Kind.	Amt. of nitro- gen per pot.				
				Gms	Gs	%	Gm	%
6346	49	Soy bean seed,	Minerals only, - - -	—	11	6.45	.71	40.31
6347	50	Soy bean seed,	Minerals only, - - -	—	11	6.57	.72	41.06
6348	51	Soy bean seed,	Minerals only, - - -	—	10	6.07	.60	37.93
6349	52	Soy bean seed,	Minerals only, - - -	—	12	6.51	.78	40.69
		Average, -			11	6.40	.70	40.00
6350	53	Soy bean seed,	Minerals + $\frac{1}{8}$ nit. ration, -	3.08	10	6.13	.61	38.31
6351	54	Soy bean seed,	Minerals + $\frac{1}{8}$ nit. ration, -	3.08	14	6.44	.90	40.25
6352	55	Soy bean seed,	Minerals + $\frac{1}{8}$ nit. ration, -	3.08	14	6.43	.90	40.18
6353	56	Soy bean seed,	Minerals + $\frac{1}{8}$ nit. ration, -	3.08	14	6.12	.86	38.25
		Average, -			13	6.28	.82	39.25
6354	57	Soy bean seed,	Minerals + $\frac{3}{8}$ nit. ration, -	6.16	12	6.02	.72	37.63
6355	58	Soy bean seed,	Minerals + $\frac{3}{8}$ nit. ration, -	6.16	14	6.24	.87	39.00
6356	59	Soy bean seed,	Minerals + $\frac{3}{8}$ nit. ration, -	6.16	14	6.42	.90	40.13
6357	60	Soy bean seed,	Minerals + $\frac{3}{8}$ nit. ration, -	6.16	13	6.50	.85	40.63
		Average, -			13	6.30	.84	39.35
6358	61	Soy bean seed,	Minerals + full nit. ration,	9.24	12	6.37	.76	39.81
6359	62	Soy bean seed,	Minerals + full nit. ration,	9.24	13	6.45	.84	40.32
6360	63	Soy bean seed,	Minerals + full nit. ration,	9.24	13	6.30	.82	39.38
6361	64	Soy bean seed,	Minerals + full nit. ration,	9.24	13	6.08	.79	38.00
		Average, -			13	6.30	.80	39.38

## EXPERIMENTS REPEATED ON SAME SOIL.

A number of attempts were made to use the soil of one year in experiments of the next year, by simply applying to the soil the same quantity of fertilizer that had been put in when first prepared. For the most part these were failures. The soil in pots 1 to 12, used for oats in 1898, was thus treated, and planted again with oats in 1899, but the growth of oats was not normal, and the crop was discarded. In 1900 clover was planted in the soil that had thus been used for oats for two years, but the results were unsatisfactory. Similar results were also obtained in 1900 in an attempt to grow timothy grass

(started from sods) in the same pots and soil that had been used for orchard grass in 1899. The experiment with Hungarian grass in 1899, which was a repetition of that of 1898, was more successful but, as pointed out on page 166, there were irregularities in this experiment also; the third experiment on the same soil was a failure.

The failures in these cases are believed to be due mainly to an excess of nitrogen resulting from the addition of more nitrogen to that left over from the fertilizer used the year or two years before; and, perhaps, in part to a bad physical condition of the soil. The reason for believing that excess of nitrogen was the main cause of failure is that the plants which first began to decline and which died first were those in the pots receiving the largest application of nitrogen, while in the pots which received no nitrogen the growth was nearly normal up to the time the experiments were discontinued and the crops discarded. The apparent injurious effects of the surplus nitrogen were first observed during the season of growth in the second oat experiment, as shown by notes made on July 20, 1899:

"Since first appearing above the soil the plants seem to have grown in reverse order from what might have been expected. That is, they varied from the smallest in those pots having the full nitrogen ration, to the largest in those having none (the mineral plots). The highest plants are now about 16 to 18 in. tall, while the plants in the full nitrogen ration pots appear to be making very slow growth, and are about 10 to 12 in. tall."

Similar notes made in connection with experiments in 1900 on timothy (from sods), which was the second, and on Hungarian grass (from seed), which was the third, in the respective soils, showed that the growth was in reverse order to the quantities of nitrogen used. The plants began to look sickly and died when they were a few inches in height, where the largest quantities of nitrogen were used, while the only pots of soil which produced anything like a normal growth were those to which no nitrogen was applied.

#### CONCLUSION.

As the pot experiments are being continued with much smaller quantities of nitrogen, it has been thought best to defer drawing any deductions until the results of the later experiments can be compared with those here reported.

SUMMARY OF RESULTS OF EXPERIMENTS WITH  
TUBERCULOUS COWS.

BY C. S. PHELPS.

In November of 1896 four Devon cows which had been condemned as tuberculous by the State Cattle Commissioners were brought to the Station for observation and experiment. When the herd of which these cattle were a part was first tested with tuberculin, in March, 1896, these particular animals failed to respond to the test, although quite a number in the herd did respond, and were condemned and killed. On October 26 and 27, 1896, the balance of the herd was retested and the four animals which were later taken for purposes of experiment responded to the test.

The following table gives the temperatures as obtained in October, 1896, in the tests made by the State Cattle Commissioners. The official numbers given the cows at that time have been retained.

TABLE 53.

*Tuberculin tests made with cows prior to their arrival at the Station.\**

NUMBER OF COW.	BEFORE INJECTION.		AFTER INJECTION.				
	8 P. M.	10 P. M.	6 A. M.	8 A. M.	10 A. M.	12 M.	2 P. M.
<i>Test made Oct. 26-27, 1896.</i>	o	o	o	o	o	o	o
1337, - - - -	101.3	101.4	100.6	101.6	103.0	104.4	104.8
1341, - - - -	101.6	101.4	100.8	101.7	102.4	104.4	105.6
1342, * - - -	102.0	101.7	99.6	101.6	102.8	104.4	105.0
1344, - - - -	101.8	101.1	102.0	102.0	105.0	105.8	105.6

\* Through the courtesy of the former Secretary of the State Cattle Commission we are able to publish the temperatures obtained in the tuberculin tests made prior to the arrival of the cows at the Station. These tests were made by Dr. L. J. Storrs.

CARE OF THE COWS AFTER THEY WERE BROUGHT TO THE  
STATION.

When the cows were brought to the Station they were isolated from other cattle, in a high, light and airy stable, with about 1,500 cubic feet of air space per cow; although later several calves which were used in the experiments with the cows occupied the same stable. Adjoining the stable was a small yard, about one-half acre in area, in which the animals were allowed to exercise several hours each day, except in very stormy or extremely cold weather. No special treatment for the disease was attempted, but good care and feed were afforded at all times.

Soon after the cows were brought to the Station plans were made to begin a series of studies and experiments relating to the progress of the disease and its infectiousness at different stages of its development. The general purpose of the experiments was to study: (1) the progress of tuberculosis in cows which apparently had the disease in a mild form when the studies began; (2) the infectiousness of the disease in different stages of development, on calves and young stock when fed upon the milk of the cows while closely associated with them; (3) the infectiousness of the milk when the calves to which it was fed were isolated from the cows. As quite full reports of the progress of the experiments have been given in the last three annual reports of the Station, only a brief summary of the work, with the results obtained, will here be given.

Early in the course of these studies plans were made by which tuberculin tests and physical examinations of the animals could be made from time to time. During the first year that the cows were under observation the tuberculin tests were made from two to three months apart, and during the last three years the tests were made twice a year, in the spring and in the early fall or winter. A rise of two degrees above the maximum temperature of the animal before injection, occurring within twenty-four hours after the injection, is considered a response to the test. All of these tests and examinations except one were made by the College veterinarians. The tuberculin tests from January 26, 1897, to July 31, 1897, were made

by Dr. George A. Waterman. One test was made in September, 1897, by Dr. L. J. Storrs, the College being temporarily without a veterinarian at that time. The balance of the tests were made by Dr. N. S. Mayo.

In the following paragraphs will be found a list of the tuberculin tests, with the dates, and the number of the reactions after the cows were brought to the Station:

January 26-27, 1897, first tuberculin test. Cows Nos. 1337, 1341, 1343 and 1344 tested. *All responded to the test.*

April 26-27, 1897, second tuberculin test. All of the cows tested. *Nos. 1341 and 1344 responded to the test.*

July 30-31, 1897, third tuberculin test. All of the cows tested, but no response.

September 27-28, 1897, fourth tuberculin test. All of the cows tested, but no response.

December 17-18, 1897, fifth tuberculin test. All of the cows tested. *No. 1344 responded to the test.*

April 11-12, 1898, sixth tuberculin test. All of the cows tested. *No. 1343 responded to the test.*

December 22-23, 1898, seventh tuberculin test. All of the cows tested, but no response.

June 2-3, 1899, eighth tuberculin test. All the cows tested. *No. 1343 responded to the test.*

December 1-2, 1899, ninth tuberculin test. All of the cows tested. *No. 1341 responded to the test.*

March 19-20, 1900, tenth tuberculin test. All of the cows tested, but no response.

September 28-29, 1900, eleventh tuberculin test. All of the cows tested. *No. 1341 responded to the test.*

#### PHYSICAL EXAMINATIONS.

On May 8, 1898, February 7, 1899, and May 26, 1900, Dr. N. S. Mayo made physical examinations of the animals and his reports are inserted here. When these reports are compared they will be found of interest as showing the progress of the disease, especially in cows Nos. 1341 and 1343.

*Report of the veterinarian, May 8, 1898.*—It is a fact well recognized that bovine tuberculosis, unless well advanced, is one of the most difficult diseases to diagnose upon a physical examination.



Of the seven animals examined four are the Devon cows that have been tested and found to respond at one time and another, and three (A, B, and D) are young calves that have been fed with the milk of the cows. The calves have not reacted to the tuberculin test, and a careful physical examination fails to reveal any indications that they have tuberculosis.

Of the four cows that have responded to the test, No. 1337 presents no symptoms of tuberculosis. She is in good flesh and looks well. Her temperature was  $102.2^{\circ}$  F., respirations full and at the rate of 12 per minute.

Cow No. 1341 is thinner in flesh than any of the others, and seems to be affected with a slight but chronic looseness of the bowels. Her temperature was  $102^{\circ}$  F., and respirations 12 per minute.

Cow No. 1343 is rather fat. She is troubled with a chronic cough, and auscultation indicates that the anterior (cephalic) lobes of the lungs, especially the right, are tuberculous. Her temperature was  $102.6^{\circ}$  F., and respirations 22 per minute.

Cows Nos. 1337, 1341, and 1343 are pregnant.

Cow No. 1344 is in good flesh. Temperature  $101.8^{\circ}$  F., and respirations 15 per minute. Nothing abnormal could be detected upon a physical examination. No enlarged glands could be detected in any of the animals examined. Of the four cows that have at some time responded to the test, Nos. 1337 and 1344 show no symptoms of the disease having developed. In No. 1341 the chronic looseness of the bowels may be considered as a suspicious symptom of a tubercular affection of the digestive tract. In No. 1343 the physical symptoms indicate tuberculosis of the lungs.

It must be remembered that all of these animals have had good care and attention, and have not been exposed to conditions or circumstances that would cause the disease to develop.

*Report of the veterinarian, February 7, 1899.*—Of the four Devon cows examined, No. 1337 does not seem to be in as thrifty condition as she ought to be, considering her care and feed. No. 1341 is not in as thrifty condition as No. 1337, and would probably be condemned as tuberculous on a physical examination. Nos. 1343 and 1344 are in excellent condition, physically, both being rather fat, and are looking well. The

only evidence of disease is found in No. 1343, her respirations not being as full and deep as they should be normally. No cough was noted in any of the animals.

*Report of the veterinarian, May 26, 1900.*—Cow No. 1337. In excellent physical condition as far as could be determined; good flesh, coat smooth and of good color, respirations 16 per minute. I was unable to detect any abnormal sounds or absence of sounds in the lungs upon auscultation. This cow is evidently well along in pregnancy.

Cow No. 1341. Thin in flesh and does not look in a thrifty condition. Coat is rough and has not shed well. A part of her physical condition may be attributed to having been in milk for some time. This cow's lungs appear to be slightly affected. Respirations 22 per minute.

Cow No. 1343. Rather thin in flesh. Coat looks some better than No. 1341, but No. 1343 coughs quite badly, and auscultation reveals considerable areas of solidification in both lungs. Respirations 36 per minute.

Cow No. 1344. Very thin in flesh, and her general physical condition is not good. She is suffering from severe lameness in the right hind leg, which appears to be due to a tubercular affection of the stifle joint. A considerable portion of this cow's poor condition must be attributed to her lameness. Respirations 22 per minute.

N. S. MAYO, D. V. S.,

*College Veterinarian.*

NOTES ON THE PHYSICAL CONDITION OF THE COWS DURING  
THE PERIOD OF STUDY, NOVEMBER, 1896,  
TO NOVEMBER, 1900.

During the first year that the animals were under observation all four cows remained in good condition and showed no outward sign of disease. Cows Nos. 1343 and 1344 had dropped calves in September or October, 1896, before they were brought to the Station. Cow No. 1341 dropped a dead calf (apparently premature by about one month) March 2, 1897. The calf was examined for tuberculosis by physical examination and by cultures made from sections taken from

several parts of the body, but these tests failed to show any sign of the disease or of the tuberculosis germs. Cow No. 1337 produced a vigorous heifer calf April 5, 1897. This calf suckled its dam for about six months and was then placed in the College herd and reared for dairy purposes. All four cows gave a fair flow of milk from the time of calving until they went dry preparatory to calving again. During the second year (1898) that the cows were under observation Cow No. 1337 remained in a good condition of flesh and appeared to be in vigorous health. She dropped a well developed calf in September, 1898, which was allowed to suckle its dam for about a year. Cow No. 1341 produced a well developed calf in August, 1898, and seemed to be in a good state of health throughout the following winter. Cow No. 1342 became quite fat during the early part of 1898. She dropped a rather small calf in August, 1898. This cow was considerably thinner than usual for three months after calving, but soon after that began to gain in flesh. Later in the fall of 1898 cow No. 1343 was noticed to have a persistent cough, which continued throughout the winter. Cow No. 1344 remained farrow during 1898, although she continued to give a good flow of milk. During the fall of 1898 she gained in flesh and appeared to be in a healthy, vigorous condition.

During the year 1899 cow No. 1337 remained in a vigorous state of health, producing a healthy calf in December of that year. The calf appeared to be vigorous and strong at birth, but was soon after attacked by scours and died in a few days. Cow No. 1341 remained in a fair state of flesh and continued to give a good flow of milk till July, 1899. At that time, while being fed green oats and peas, she was attacked by scours and began to "run down" rapidly. She ceased giving milk for a short time, but when placed on dry feed began to regain her flesh and milk flow. This cow remained in a fair state of health during the fall of 1899, although she had a somewhat irregular tendency to looseness of the bowels. Cow No. 1343 continued to give a fair flow of milk during the spring and summer of 1899, although she was not as fat as during 1898. The cough which was first noticed late in the fall of 1898 increased in severity during the following winter. During the spring of 1899 she coughed badly after eating dry feed.

or when made to exercise vigorously. This cow produced a vigorous calf in December, 1899; the calf was soon after attacked by a mild case of scours, from which it recovered in a few days. Cow No. 1344 gave a fair flow of milk during the early part of 1899 and seemed to be in a vigorous state of health. Sometime during the summer of 1899 she showed lameness in the stifle joint of the right hind leg, but this gave her little trouble. This cow calved in October, 1899; the calf was weak at birth and refused to eat. It died about a week after birth. The cow gave a good flow of milk for several months after calving, but was thinner than usual.

During the early part of the fourth year that the cows were under observation three of the four began to show marked signs of decline. Cow No. 1337 remained in a good state of flesh, had a sleek coat and continued to give a good flow of milk, and appeared brighter and more active than any of the others. This cow appeared to be in a vigorous state of health when killed in November, 1900. Early in the year (1900) she developed a slight cough, but otherwise appeared to be in perfect health. Cow No. 1341 produced a healthy calf in February, 1900, and gave a good flow of milk for several months after calving; but during the spring and summer of 1900 she lost flesh rapidly, until her flanks were hollow and her ribs protruded plainly; her coat became rough, her eyes dull and sunken, her cough increased and her breathing was shorter and more frequent. She continued to scour intermittently, and when killed in November, 1900, she was generally emaciated, although continuing to give milk up to the time she was slaughtered. Cow No. 1343 gave a fair flow of milk during the early part of 1900, although she was losing flesh. During the spring and summer her cough increased in frequency and her breathing was short and hurried. During the fall of 1900 she lost flesh rapidly, had a rough coat, sunken eyes and protruding ribs. She lost her appetite and in October ceased to give milk, and when slaughtered in November was greatly emaciated. Up to within a year of the time of slaughtering this cow had been the fattest and sleekest of the four. During the early part of 1900 cow No. 1344 gave a good flow of milk, but rapidly lost flesh and developed a severe cough, which,



during the spring of 1900, was especially noticeable when the cow was made to exercise vigorously. The lameness in the stifle joint of the right hind leg increased in severity and became very troublesome to the cow. She lost flesh during the summer and fall and although not as emaciated as Nos. 1341 and 1343, was quite thin, had a rough coat, and appeared to be in a bad physical condition when slaughtered in November, 1900.

#### POST MORTEM EXAMINATIONS.

The following is the report of Dr. N. S. Mayo regarding the condition of the disease in the different animals as shown by the post mortem examinations.

Cow No. 1337, mediastinal lymphatics tuberculous, nodule found in right lung, other organs normal.

Cow No. 1341, both lungs found diseased, two-thirds of right and one-half of left lung filled with tuberculous tissue; mediastinal lymphatics diseased.

Cow No. 1343, both lungs badly diseased, almost solidified with tuberculous tissue; pleural costalis covered with tubercles; mediastinal lymphatics tuberculous, and mesenteric lymphatics all badly tuberculous. Tubercles were also found on the rumen and diaphragm.

Cow No. 1344, mediastinal lymphatics diseased, and abscess in left lung.

#### SUMMARY OF THE RESULTS OF FEEDING THE MILK OF THE COWS TO CALVES.

During the larger part of the four years that these tuberculous cows were at the Station the milk of some or all of them was fed to calves. In some cases the calves fed were the offspring of the tuberculous cows, while in other cases they were from cows which careful tests had indicated were free from the disease. In some cases the calves were allowed to associate with and to suckle their dams, while in other cases they were separated from the cows and were fed from a pail.



In the earlier feeding tests with the milk of the diseased cows the calves were kept in the same stable with the cows, one object of these experiments being to study the infectiousness of the disease when the calves were associated with the cows while being fed their milk. The results of the first two years' feeding tests show that, while the milk of each of the four cows was fed to separate calves in periods ranging, in the different cases, from three months to one year and four months, in no case was there any indications of the disease in the calves during the feeding period. The calves were kept with the cows nearly two years. One of these calves responded to the tuberculin test about five months after the feeding period of sixteen months was ended, and was found upon post mortem examination to be very slightly diseased. These results would seem to indicate that while the cow has the disease in its earlier stages, and if the udder is not affected, the danger of the spread of the disease is limited.

During the late summer and early fall of 1898, three of the four cows produced calves, and it was decided to feed their milk to their offsprings. The offspring of one cow (1341) and the offspring of a tuberculous cow from another herd were selected for a comparison of the infectiousness of pasteurized and raw milk from the same cow. About half the milk from one cow was heated to about 170° F. and fed to her offspring, and the balance of the milk, in its natural state, was fed to the offspring of the other tuberculous cow. The calves were isolated from the cows, being kept in the main part of the barn, while the cows were kept in the basement. Neither of the calves responded to the tuberculin test made after a feeding period of about ten months. By a misunderstanding both of the calves were fed the unpasteurized milk of the cow for a period of three weeks (following the tuberculin test) after which they were turned out to pasture for about five months. Three weeks after being returned to the stable with the cows the calf which had been fed the pasteurized milk (except for three weeks) responded to the tuberculin test, while the other calf failed to respond until some five months later. The conditions of this test would seem to show that the calf which had been fed pasteurized milk acquired the germ of the disease

either during the three weeks while the unpasteurized milk was being fed, just before the calf went to pasture, or else during the three weeks after being returned from pasture, just prior to responding to the tuberculin test. The fact that the other calf, also an offspring of a tuberculous cow, did not show any signs of the disease six months after a feeding period of ten months with the unpasteurized milk, but did respond after being associated with the cows for several months more, would seem to show that the milk had not proved infectious.

Two other calves were fed the milk of their dams from August and September, 1898, until the next June. Thus one was fed a period of over nine months and the other a period of ten months while associated with the cows. At the end of ten months' feeding in one case and nine and one-half in the other neither of the calves responded to the test. One calf was at pasture from June 24 to November 13, while the other remained in the stable with the cows. Both responded to the test on December 2, following, three weeks after one of the calves was returned from the pasture. These tests would seem to show that either the milk is very slow in transplanting the germs of the disease, or that the development of the disease is slow when the germs are transmitted by the milk, or else that the disease was transmitted by other means due to the association of the calves with the cows.

Two more calves were fed the milk of the two other cows. One calf (I) was from a tuberculous cow in another herd and the other one (K) was from cow No. 1343. Calf I was kept in the same stable with the cows, and after being fed the milk of cow No. 1344 for a period of ten weeks responded to the tuberculin test. Calf K was fed the milk of its dam (No. 1343) while isolated in a room in another part of the barn. After a feeding period of nearly three months this calf responded to the tuberculin test.

In this series of tests five calves were fed the milk of the tuberculous cows, in periods varying from ten weeks to ten months. Two of these tests were made from one to one and one-half years later than the other two, and the disease had in the meantime made marked progress in at least three of the cows.

These tests would seem to show that as the disease becomes more advanced in the cows their milk is more infectious, and there is danger to the health of other animals, both from the use of the infected milk and in association with the diseased animals.

Judging from the results of the physical examination made early in May, 1900, and from the general condition of the cows, the disease was reaching its more advanced stages, in at least three of the cows, by the spring of 1900. In May of that year it was decided to test the question of the infectiousness of the milk of the tuberculous cows upon calves from the non-tuberculous cows when the calves were isolated at pasture. Three calves from the cows in the College herd were selected which were believed to be free from the disease. These calves were placed in a small pasture near the Station barn. Calf L was fed the milk of cow No. 1337; calf M was fed the milk of cow No. 1341, and calf N the milk of cow No. 1343. The milk was transferred to another lot of pails than those into which it was milked, and the attendant was instructed to change his outer garments before passing from the barn to the calf pasture, and all possible means were taken to prevent the transmission of the disease in any way except by the milk. The calves were tested with tuberculin May 24-25, about three weeks after the feeding period began, and again September 28-29, after having been fed over four and one-half months. None of the calves responded to either of these tests. The calves were not fed milk after the September test, but were kept at pasture until late in the fall. They were then given the shelter of a shed separate from all other stock. Calf M was found to be ailing on November 28 and died November 29. An examination by Dr. Mayo revealed a congested condition of the stomach, kidneys and bladder, indicating some form of poisoning. An examination of the lungs also indicated tuberculosis as follows: "Tuberculous nodule in the right lung, calcified, and mediastinal lymphatic tuberculous." During the winter the two other calves were kept in the basement of a barn separate from all other cattle. In February, 1901, these calves failed to respond to the tuberculin test, and in May were sent to pasture with some other stock.

The general conditions and results of this test were as follows: Three calves, while at pasture, were each fed the milk of a separate cow. Calf L, was fed the milk of a cow in a slightly diseased condition, and at the end of a feeding period of about four and one-half months, and again five months later, failed to respond to the tuberculin test. Calf M was fed the milk of a badly diseased cow, and at the end of a feeding period of four and one-half months failed to respond to the tuberculin test; but when examined two months later, after having died apparently from poisoning, did show a slightly tuberculous condition. Calf N was fed the milk of a badly diseased cow for a period of about four and one-half months, when it failed to respond to the tuberculin test, and did not respond to a similar test five months later. Calves L and N were sent to pasture when about one year old and appeared to be in a vigorous state of health.

#### CONCLUSION.

*The results of these experiments with tuberculous cows and the use of their milk for feeding calves coincide with the general results of European observations, and indicate that the danger of the spread of tuberculosis through the milk of diseased animals is not so great as has often been supposed. In the earlier stages of the disease, and when the udder is not affected, the danger from the use of the milk appears to be limited. But when the udder is affected, or when the disease is so far advanced as to be indicated by outward signs or marked physical symptoms, the infectiousness of the milk is increased, and the danger in using it as food for man or animals is greater.*

*From what has been said, however, it is not to be understood that the farmer may neglect any case of tuberculosis in his herd if it is not in the advanced stages, or if the udder of the cow is not affected. As a matter of fact, it is practically impossible for him to tell when any animal that reacts to tuberculin may acquire tuberculosis of the udder. There is danger enough in the fact that the cows may acquire the disease from one another at all, no matter how likely or unlikely they may be to do so. Therefore, if the farmers do not want their dairy industry menaced and perhaps*

*seriously injured by the wider spread of tuberculosis among their herds, it is of the utmost importance that each one use every effort to free his herd from the disease.*

*Cows should be examined carefully for physical symptoms of the disease and be tested with tuberculin, and any that respond at all should be looked upon with suspicion. Whatever disposition is finally made of those that are diseased, they should be kept at all times completely separated from those that are not, and the non-affected animals should be carefully watched and be tested with tuberculin at least once a year. Only in this way can new cases be discovered in their earlier stages. Unless the farmers can be brought individually to appreciate the gravity of the matter to themselves and the menace to their industry, and to take measures for destroying the disease in their own herds, the history of bovine tuberculosis in Europe, where in some regions the greater portion of the cows are infected, may easily be repeated in this country.*



## METEOROLOGICAL OBSERVATIONS AT STORRS AND GENERAL WEATHER AND CROP REVIEW.

REPORTED BY C. S. PHELPS.

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The meteorological observations made by the Station during 1900 were similar to those of previous years. The Station equipment at Storrs consists of the ordinary instruments for observing temperatures, pressure of the air, humidity, rainfall, snowfall and velocity of the wind, similar to those in use by the Weather Bureau of the United States Department of Agriculture. A summary of the observations made at Storrs is given in Table 54.

In addition to the records made at Storrs, the rainfall for the summer season (May 1 to October 31) was recorded by nine farmers in different parts of the state in coöperation with the Station. These measurements are given in Table 55, together with those supplied by thirteen stations of the New England Meteorological Society.

The total precipitation at Storrs for the year, 48.6 inches, was about 3.2 inches more than the average for the past twelve years, but was very close to the general average for the state as computed from the records of the New England Meteorological Society covering periods of from five to thirty years. The rainfall was especially heavy in February and March. For the season from May 1 to October 31, the precipitation at Storrs, 19.5 inches, was about 3 inches below the average for the past twelve years, and was also below the general average of observations made in different parts of the state during the same years. There was a general deficiency in the rainfall during July, August and September, which affected all those crops that made most of their growth during that period. Vegetables, fruits and even corn were considerably damaged. The precipitation during November was heavy, so that springs and streams were generally well filled when winter began; and in

December also it was especially heavy. The heavy precipitations during the earlier and later months brought up the total for the year above the average, in spite of the severe drought during the summer.

The average temperatures for January and February were slightly above the averages for those months as recorded at Storrs, while that of March was slightly below the average. April was cold, and the spring was rather backward. The last killing frost, which was unusually severe, occurred May 11, with a minimum temperature of  $25^{\circ}$ . The temperature for June was about normal, while that for July and August was above the average for Storrs for the past twelve years. The first killing frost in the fall did not occur until October 18, so that the season was especially favorable for late maturing crops. The length of the growing season between May 11 and October 18, 158 days, was twelve days more than the average at Storrs for the past twelve years. October was generally mild and favorable for the harvesting of crops. The fall season was rather short, as considerable snow fell on November 9, and the month on the whole was cool.

The following general summary of the meteorological phenomena of New England in 1900, and the general review of the crop season, given in the annual summary of the Climate and Crop Service of the United States Weather Bureau, although pertaining to the whole section in the main apply very well to conditions in Connecticut:

*General summary.*—The year 1900, in New England, was marked by meteorological conditions which were greatly at variance, in several of the elements, from those generally recorded in this section. It opened mild and without the severe storms usually experienced at that season of the year. This was succeeded by a period of continued cold weather, with the average temperature considerably below the normal, and precipitation generally in excess, which extended through May. These conditions resulted in a backward spring, which delayed farming operations. June was practically normal and a very pleasant month. A severe and general drought, which had its beginning in July, continued through September. The temperature during this lengthy period was continuously and largely in excess of the normal for those months. The abnormally warm weather also continued through October and November, the excess of temperature being especially phenomenal in the former month, when the monthly mean was about six degrees above the normal. The long duration of hot, dry weather in many instances proved disastrous to crops. The weather of the year, briefly and summed up as a whole, was unfavorable to agricultural and commercial interests, and has seldom been paralleled in the official records.

## REVIEW OF THE CROP SEASON.

Owing to the unusually fine weather which prevailed through March the season opened auspiciously, and, according to general estimates, slightly in advance of the average. In the southern portion of the district the ground was free of snow by the close of March, and frost was out of the soil by the end of the first week of April. Active farming operations began promptly, and plowing and preparing the soil for seeding and planting progressed rapidly. In the northern New England states, however, the ground was not bare until the beginning of the third week of April, and farm work there was somewhat delayed. By the close of April plowing was about completed in the northern portion of the section, though little planting had been done; while for the southern states both were completed, oat fields were green and stock were grazing on the pastures.

The weather conditions of May were, generally speaking, unfavorable to vegetable growth, and less favorable than usual for farm operations. The temperature was unseasonably low, and ice formed on ponds and the ground froze in parts of each state, resulting in great and general damage to tender vegetation and to fruit buds. The supply of precipitation, up to the close of May, was sufficient for the needs of the soil.

June opened with improved weather conditions. The high temperature was especially favorable to the germination of planted seeds and to growing crops. A moderate drought began about the middle of the month and increased, and at the close there was a general need of rain. The month closed with crops, as a whole, in fairly satisfactory condition; corn a week to ten days late; fruit very promising.

The drought increased during July with a general excess in temperature. These conditions were unfavorable to crops, except tobacco, which improved. The dry weather caused apples to blight and drop; also an increase in insect pests of all kinds.

The unfavorable weather conditions continued through August. The dry weather seriously affected all vegetation. It was, however, favorable to harvesting and threshing grain, and for housing and cutting tobacco. At the close of the month the ground was too dry for plowing and fall seeding.

The condition of growing crops remained unfavorable until the 15th of September, owing to a continuance of the almost unprecedented and general drought. Copious rains during the latter half of the month relieved the drought and prepared the soil for cultivation and for seeding. A high wind was felt through the section on the 12th, blew off a large portion of the apples, and, in many instances, damaged the trees.

October, the closing month of the season, was very favorable to all farm operations. Abundant rains maintained the soil in excellent condition. These rains, combined with the high temperature, were favorable to seeded crops, pastures and meadows. Crops generally were secured and housed in excellent condition. The season, viewed as a whole, was less favorable to crops than the average in New England. Hay was a short crop; early potatoes were inferior, and the crop was below the average. Apples were a good crop; probably in excess of the average yield. Corn and beans were medium crops, while buckwheat was light. Tobacco was an exception to all other crops, being, according to reliable estimates, the best ever grown in New England. Owing to the early maturing of crops very little, if any, damage resulted from frost.

TABLE 54.

*Rainfall during six months ending October 31, 1900.*

LOCALITY.	OBSERVER.	INCHES PER MONTH.						Total.
		May.	June.	July.	August.	September.	October.	
Canton, - -	G. J. Case, - -	6.05	3.81	4.65	2.55	2.56	4.15	23.77
Clark's Falls, - -	E. D. Chapman, -	5.08	0.89	2.58	1.98	3.29	3.06	16.88
Colchester, - -	S. P. Willard, -	3.93	1.80	2.43	0.86	2.48	3.92	15.42
Cream Hill, - -	C. L. Gold, - -	5.13	4.42	6.09	2.18	1.75	2.73	22.30
E. Windsor Hill, -	J. N. Fitts, - -	4.09	4.78	3.31	2.58	1.65	2.15	18.56
Falls Village, - -	M. H. Dean, - -	5.58	4.45	5.02	1.87	1.85	2.41	31.08
Hartford, - -	H. H. Moore, - -	5.41	3.04	4.83	2.65	1.72	2.84	20.49
Hawleyville, - -	E. N. Hawley, -	5.98	4.31	3.02	2.62	3.00	4.25	23.18
Lebanon, - -	E. A. Hoxie, - -	5.08	2.58	2.68	0.74	2.72	4.04	17.84
Madison, - -	J. D. Kelsey, - -	2.95	1.57	2.84	1.91	2.99	3.13	23.21
Middletown, - -	A. P. Bryant, - -	3.62	2.08	2.92	1.89	2.75	3.82	17.18
New Haven, - -	Weather Bureau, -	3.30	1.79	2.28	0.90	2.10	2.03	12.40
Newington, - -	J. S. Kirkham, -	5.92	3.37	2.74	2.72	1.98	3.31	20.04
New London, - -	J. R. May, - -	4.84	1.90	1.46	0.89	4.03	1.59	14.71
Norfolk, - -	G. O. Stanard, - -	5.30	3.21	6.23	2.20	1.51	2.90	21.35
N. Grosvenor Dale,	Grosvenor D. Co.,	5.84	3.66	4.16	1.57	2.09	4.10	21.42
Norwalk, - -	G. C. Comstock, -	3.62	2.03	4.30	2.25	3.44	3.47	19.11
Southington, - -	Lumen Andrews, -	5.15	3.13	2.70	1.90	2.20	2.95	17.03
So. Manchester, -	K. B. Loomis, - -	5.34	4.06	2.87	1.45	2.09	3.24	19.05
Storrs, - -	Experim't Station,	4.91	4.32	2.76	2.03	2.27	3.21	19.50
Voluntown, - -	Rev. E. Dewhurst,	4.48	2.23	2.58	2.00	3.10	2.80	17.19
Waterbury, - -	N. J. Welton, - -	4.39	3.02	3.10	2.09	2.15	3.59	18.34
W. Simsbury, - -	S. T. Stockwell, -	5.44	2.79	3.99	2.67	2.37	3.64	20.90
Average, - -	- - - -	4.84	3.01	3.46	1.93	2.44	3.19	19.65

TABLE 55.  
*Meteorological Summary for 1900.*  
 [Observations made at Storrs by the Station.]

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Mean.	Total.
Highest barometer, -	30.63	30.69	30.52	30.49	30.34	30.19	30.20	30.31	30.36	30.61	30.68	30.50	30.46	—
Lowest barometer, -	27.17	28.91	29.15	29.46	29.44	29.60	29.54	29.86	29.48	29.61	29.16	29.05	29.37	—
Mean barometer, -	30.14	29.94	29.93	29.85	29.95	29.93	29.25	30.02	30.07	30.19	30.04	30.07	29.95	—
Highest temperature, -	56	56	52	78	90	89	93	92	92	80	70	56	75	—
Lowest temperature, -	2	-7	2	20	25	40	52	47	37	25	16	3	22	—
Mean temperature, -	27	26	30	46	55	66	71	69	64	54	41	29	48	—
Relative humidity, -	—	—	—	66	64	71	75	76	80	84	—	—	—	—
Total precipitation—-inches, -	3.42	7.31	6.43	2.67	4.91	4.32	2.76	2.03	2.27	3.21	6.79	2.22	—	48.64
Number of days with .01 inch or more precipitation, -	10	9	9	8	11	9	9	10	8	6	14	6	—	109
Number of clear days, -	11	8	16	18	9	11	13	13	8	7	6	8	—	128
Number of fair days, -	10	10	9	4	10	13	11	10	11	9	7	13	—	117
Number of cloudy days, -	10	10	6	8	12	5	7	8	8	10	4	6	—	94



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## PUBLICATIONS OF THE STATION.

The publications of the Station will be mailed free to all citizens of Connecticut, and to Granges, Farmers' Clubs, and other agricultural organizations, that ask for them, and so far as circumstances permit, to those who apply from other states.

To meet requests constantly received for information regarding the publications, a supplement to the present Report has been published, giving a list of the Annual Reports, Bulletins, and Reprints issued by the Station since its organization. The list includes that portion of the table of contents of each Report which gives the titles of the articles contained in it; the number and title of each Bulletin; and the title of each Reprint with the number of the Report from which it is taken. In addition to these, the titles of several Reprints from the Reports of the Connecticut Board of Agriculture concerning the work of the Station are also given. In the list those publications of which copies are no longer available for distribution are appropriately marked.

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